A COMPARISON OF PLASTER, DIGITAL AND RECONSTRUCTED STUDY MODEL ACCURACY

Dissertation submitted to

THE TAMILNADU Dr.M.G.R.MEDICAL UNIVERSITY

In partial fulfillment for the degree of

MASTER OF DENTAL SURGERY

BRANCH V

ORTHODONTICS AND DENTOFACIAL ORTHOPAEDICS

CERTIFICATE

This is to certify that this discussion titled **'A COMPARISON OF PLASTER, DIGITAL AND RECONSTRUCTED STUDY MODEL ACCURACY'** is a bonafide record of work done by **Dr.Thirunavukkarasu Geetha** under my guidance during her postgraduation study period between 2008-2011.

This dissertation is submitted to **THE TAMIL NADU DR. M.G.R. MEDICAL UNIVERSITY,** in partial fulfillment for the degree of **Master of Dental Surgery** in Branch V-Orthodontics and Dentofacial Orthopaedics.

It has not been submitted (partially or fully) for the award of any other degree or diploma.

Guided By

Anand. M.K

Dr. M. K Anand M.D.S.,
Reader,
Department of Orthodontics and
Dentofacial Orthopaedics
Ragas Dental College & Hospital
Chennai

Head of the Department

N.R. 30/12/10

Dr.N.R.Krishnaswamy M.D.S.,
M.Ortho R.C.S.(Edin), Dip.N.B.(Ortho)
Diplomate of Indian Board of Orthodontics
Professor and Head
Department of Orthodontics and Dentofacial
Orthopaedics
Ragas Dental College & Hospital
Chennai

RAGAS DENTAL COLLEGE
Chennai

PROFESSOR & HEAD
Dept. of Orthodontics
RAGAS DENTAL COLLEGE & HOSPITAL
2/102, East Coast Road
Uthandi, Chennai-600 119

Principal

Dr. S. Ramachandran, M.D.S.,
Ragas Dental College & Hospital,
Chennai

PRINCIPAL
RAGAS DENTAL COLLEGE AND HOSPITAL
UTHANDI, CHENNAI-600 119

ACKNOWLEDGEMENT

*First of all, I wish to thank **GOD** for his love, grace, mercy and wisdom which form the foundation of my life and all my work.*

With deep satisfaction and immense pleasure, I present this work undertaken as a Post Graduate student specializing in Orthodontics and Dentofacial Orthopaedics at Ragas Dental College and Hospital. I would like to acknowledge process of working on this dissertation which has been a wonderful and enriching learning experience.

*I am greatly indebted to my professor **Dr. N.R.Krishnaswamy**, M.D.S., M.Ortho RCS. (Edin), Diplomat of Indian board of Orthodontics, Professor and Head, Department of Orthodontics, Ragas Dental College and Hospital, Chennai., for his guidance and support. He is a pioneer with vast teaching experience who sets an example by his dedication, focus and determination. His words have imprints of genius. His constant guidance in the academic front during my studies has helped me a lot. I have been fortunate to study under his guidance and support. These memories definitely would cherish throughout my life.*

*I would like to extend my heartfelt gratitude to **Dr.S.Venkateswaran,** M.D.S., D.N.B. (Ortho) , Professor, Department of Orthodontics and Dentofacial Orthopaedics, Ragas Dental College and Hospital, Chennai for his untiring efforts, insight and perspective that has been of invaluable help. His patience, technical expertise, industrious and yet unpretentious nature has always been revered. He paved the royal road for perfect understanding and his pleasant supportive demeanor, simplicity, innovative approaches and impetus throughout the duration of my course has encouraged me in many ways.*

*I would take pleasure to thank my Professor **Dr. Ashwin George**, M.D.S, D.N.B. (Ortho),, Department of Orthodontics and Dentofacial Orthopaedics, Ragas Dental College & Hospital, Chennai for his support and encouragement and constructive feedback which he rendered with zeal throughout my postgraduate course. His* *expert advice and unique style have been helpful in improvising my work and also aided to develop the necessary skills, not only in the profession but also as an individual too. I am proud to have an eminent professor like him during my post graduation days and express my sincere thanks to him.*

I express my deepest gratitude to my teacher and guide ***Dr.M.K.Anand MDS****, Reader, Department of Orthodontics and Dentofacial Orthopaedics, Ragas Dental College & Hospital, Chennai for sharing his unparalleled academic & clinical knowledge and constant encouragement and expert advice and motivation who made me work to get the thesis to its best form. I am very grateful to sir for being helpful and instrumental in correcting my work in every part of my thesis and for his whole hearted co-operation instead of his busy schedule for making this thesis a grand success. This thesis is a virtual reality of sir's dogma and foresight in three dimensional field.*

I also wish to convey my heartfelt thanks to Professor, ***Dr.B.Vikraman,****MDS Professor, Department of Oral & Maxillofacial Surgery, Ragas Dental College, Chennai. I express my personal thanks to sir for being so tolerant, encouraging and understanding. I shall remain forever indebted to him for his valuable guidance and input throughout the digital analysis, a portion of my dissertation without which I would have never accomplished this particular research. He has been instrumental in introducing the MIMICS software to our college, using which a lot of 3D virtual work is being done in the field of MRI and CT data simulation.*

It is a pleasure to record my gratitude to Dr. Shahul Hameed(Associate professor) , Dr. Jayakumar(Reader), Dr. Shakeel Ahmed(Reader), Dr. Rekha(Sr Lecturer) , Dr. Rajan(Sr Lecturer), Dr.Shobana(Sr Lecturer) and Dr. Biju(Sr Lecturer) for their whole hearted co-operation, valuable suggestions and for being very amicable and helpful throughout my postgraduate course.

I am greatly indebted to ***Dr. S. Ramachandran,*** *Principal, and* ***Mr.Kanakaraj*** *chairman, Ragas Dental College and Hospital, for allowing us to use the, scientific literature and research facilities of the college.*

I would like to express my gratitude to **Dr. Saravanan,** Radiologist, Saravana Advanced MRI and CT Scan, Chennai for undertaking all the work with zeal inspite of his busy schedule. I would like to thank **Mr. Grace Rajan & Mr. Sathish**, CT & MRI Technicians, for helping me in taking CT scans.

I would like to thank **Mr. Bhoopathi** for his help and efficiency in preparing the statistical analysis.

I would like to thank my senior colleagues **Dr. Preethi, Dr. Biju, Dr. Sam, Dr. Karthik Mani, Dr. Prabhu, Dr. Rajkumar, Dr. Chinthan and Dr. Kaberi** and my beloved batchmates **Dr. Amey, Dr. Fayyaz, Dr.Goutham, Dr. Subu, Dr. Vashi, Dr. Kavitha and Dr. Ritika** for being with me all throughout my course and for being a constant source of encouragement and support at every step. I will remember all that we shared together. I wish each one of them success and happiness as we move forward from here.

I also extend my gratitude to my junior colleagues **Dr. Saravanan, Dr. Vinod, Dr. Ashwin, Dr. Sheel, Dr. Ayush, Dr. Sreesan, Dr. Mahalakshmi, Dr. Sabitha, Dr. Siva, Dr. Vijay, Dr. Arthi, Dr. Sakthi, Dr. Deepak, Dr. Ravanth, Dr. Manikandan and Dr. Ashwin.**

At this moment I take the opportunity to thank our non teaching staff **Mrs. Marina, Mr. Rajendran, Mr. Ashok, Mr. Kamaraj, Mr. Mani, Mr.Baskar, Sisters Lakshmi, Rathi, Kanaka, Haseena, Shalini, and Divya** for their help and co-operation throughout my postgraduate course.

There are no words which can equalize the love, affection, dedication and sacrifice of **my parents, my husband, my brothers and my daughter and my in-laws** have done for me. Their love, understanding, support and blessings, sacrifices are the reasons for me to be what I am today. I would like to dedicate this work to my mother, father and my husband for their constant encouragement.

CONTENTS

Introduction

INTRODUCTION

Since the beginning of modern orthodontics more than 100 years ago, plaster casts have been used to reproduce the patient's dentition for diagnostic, therapeutic and research purposes. These study models have served as a key record of tooth size, dental morphology, arch form, local soft tissue anatomy and the relationship of the jaws.

These gypsum based study models are heavy, bulky and are labor-intensive to produce. The fragility of study models is a constant cause for concern; it can also be difficult and time consuming to measure in plaster model[2]. In addition, study model storage and retrieval is in complete contradiction to the benefits afforded by digital photographic and radiographic image storage and retrieval.

In an age of increased demand on the orthodontist for interdisciplinary care, second opinions and transfer of records for continuing of care, the limitations of stone casts have become increasingly apparent. Legislation relating to the retention of patient records after the completion of treatment has lead to large demands on space for storage that has prompted the development of alternative methods of recording occlusal relationships and electronic storage of records.[2] In late 1999 OrthoCAD (Cadent, Carlstadt, NJ) developed and released to market Virtual Digital Dental casts. Then in early 2001, emodels (Geo Digm, Chanhassen, Minn) came to market. Since then, hardware and software refinement has lowered costs and thus increased the utilization of virtual models[9].

Three dimensional digital study models was developed not to replace stone casts, but in an attempt to remove the limitations imposed by the traditional casts[34]. Substitution of plaster orthodontic models with these new virtual counterparts can benefit orthodontics in various ways like digital models are easily accessible on the computer and can be retrieved instantly, provides economical storage, eliminates the problems associated with model breakage, enables accurate, simple diagnostic set ups, treatment simulation and it can be send anywhere in the world through internet[9] which facilitates ease of communication with patients and colleagues. Magnetic and optical storage of digital model is particularly efficient and cost effective when compared to traditional study models[34].

The development of Computer Aided Designing and Computer Aided Manufacturing (CAD/CAM) system using various three dimensional (3D) measuring systems in the manufacturing industry has been followed by the use of a CAD/CAM system in dentistry using laser scanning technique. Previous studies showed that the dimensional accuracy of laser surface scanned digital models is within about 0.05mm[45]. Rapid prototyping technologies allow the production of physical models from 3D digital data. An accuracy of Stereolithography (STL) models based on computed tomography (CT) data of $\pm$ 0.5mm can be reached[22].

Three dimensional imaging of dental tissues will have a major impact in dentistry if the images are accurate[11]. Interactive three dimensional images of the soft and hard tissues of dental patients (virtual dental patients) will provide quantitative evidence to aid dentists in diagnosis, treatment planning and outcome assessment. If these images are not accurate, the prime purpose will be compromised. However clinical accuracy requirements vary for different chair side and laboratory dental procedures. Possibly, the most stringent accuracy requirements are for inter occlusal contacts, because most dental patients are sensitive to 0.020mm changes in their occlusal anatomy[11]. Hence the objective of this study is to assess the accuracy of plaster model, digital and reconstructed study model.

Aims and Objectives of the study:

1. To assess the reproducibility of a conventional method of using a hand held vernier caliper to measure plaster study models.
2. To assess the efficiency and reproducibility of converting plaster study model into a 3D digital study model (virtual model), using spiral computed tomography.
3. To assess the reproducibility of measurements made on 3D digital study models captured using spiral CT scan using Materialize Interactive Medical Image Control System (MIMICS) software.
4. To compare the accuracy of measurements made on the 3D digital study models and plaster study models of the same dentition.
5. To evaluate the feasibility of fabricating accurate 3D physical models from the 3D data by rapid prototyping (RP) process.
6. To compare the accuracy of 3D reconstructed models with plaster and digital study model of the same dentition, and to assess reproducibility of measurements made on reconstructed model using Vernier caliper.

Null Hypotheses:

1. There is no difference in dimensional accuracy of 3D digital study models captured with spiral CT scan technique described and the plaster study models.
2. There is no difference in the dimensional accuracy of reconstructed model replicas fabricated from the 3D digital models by RP, and plaster study models.

Review of Literature

REVIEW OF LITERATURE

J.S.Bill et al [22] 1995 manufactured stereolithographic model of anatomical structures from the computed tomography digital data using computer aided manufacturing (CAM) technology. In this study CT data acquisition was performed using a SONATOM PLUS S with section intervals of 1mm, section thickness in spiral mode of 2mm and 512 X 512 matrix for sufficient resolution. Data transfer was provided by laser disc, image processing was performed using a medical image processor and the advanced version of an image processing software (Kon form, KOLN, Germany) to prepare STL. The models were fabricated by the SLA-250 stereolithographic unit by polymerization of liquid U-V sensitive resin using a UV laser beam. The manufactured STL models had high precision and accuracy and aided in accurate treatment planning.

Eufinger et al [13] 1995 described Computer aided designing and manufacturing (CAD/CAM)-techniques based on helical computed tomography (CT) data, which was successfully used for the prefabrication of prostheses. An individual computer based 3-dimensional model of the bony defect is generated after acquisition, transfer and evaluation of the CT data; from this freeform surface geometry, an individual and "idealized" prosthesis-geometry was derived and fabricated by a numerically controlled milling machine using modern industrial CAD/CAM-systems and design software. The margins of this prosthesis-geometry are generated by the borders of the defect and the surface by considering the non-affected neighboring contours.

Takayuki Kuroda et al [45] 1996 used three dimensional dental cast analyzing system using laser scanning instead of manual measurements. The attributed advantage of this system are high speed measuring and processing, high accuracy besides the conventional linear and angular measurements of dental cast, they are also able to demonstrate the size of the palatal surface area and the volume of the oral cavity. Disadvantage of this system is the impossibility of the sampling beneath the overhangs and also parallax angle between laser emitter and receiver causes blind region around deep grooves with an overhang.

Schrimer, William A. Wiltshire et al [42] 1997, compared manual and computer aided space analysis. In this study they have measured manually mesiodistal width of all the teeth with vernier caliper and scanned the models on a Photostat (Xerox machine). The scanned models were digitized with dedicated computer aided software and made measurements. They concluded that the computer aided measuring is reliable but, accurate mesio-distal measurement cannot be made from photocopies of dental models. Manual measurements that use calibrated gauge produce the more accurate, reliable and reproducible results. The mean arch length measurements differed by 4.7 mm in maxilla and 3.1mm in the mandible. This difference between manual and digitized analysis may be due to photocopying process. They regarded that the measurement difference between alternative measurement methods of less than 0.20mm as clinically acceptable.

Kevin H.Y. Mok and Michael S.Cooke et al [23] 1998, did a comparative space analysis study between sonic digitization (Digi Graph workstation) and the digital caliper. They compared the reproducibility of the mesio-distal total tooth width and the arch perimeter values, on plaster casts, given by the Digi graphTM work station and by digital calipers. They found that there was an overestimation of the total tooth width by 1mm in mandible and 0.5 mm in maxilla and an arch perimeter discrepancy of 1.6mm in the mandible and 0.4 mm in the maxilla when using sonic method. They have concluded that sonic digitization was not as reproducible as digital caliper and its clinical usefulness in evaluating the space problem of an individual malocclusion should be interpreted with caution.

Marcel0 G.P. Cavalcanti et al [27] 1999 stated that linear measurements done on the 3D CT with the CAD software is accurate. He evaluated the measurement accuracy of three-dimensional (3D) volumetric images from spiral computed tomography (CT) in vitro. The study sample consisted of nine cadaver heads that were submitted to an impact force by a special device to promote blunt traumatic craniofacial fractures. The heads were subsequently scanned by a spiral CT scanner. The visualization software was used to make interactive linear measurements on the 3D images. Measurements were made on the images twice by two observers, based on conventional craniofacial anatomic landmarks. The soft tissues were subsequently removed, and the same measurements were repeated on the cadaver heads with an electromagnetic digitizer. It is concluded that measurement of the skull and facial bone landmarks by 3D reconstruction is quantitatively accurate for surgical planning and treatment evaluation of craniofacial fractures.

Nobuyoshi Motohashi and Takayaki Kuroda et al [31] 1999 applied 3D computer aided designing system in diagnosis and treatment planning in orthodontics and orthognathic surgery. This system comprises a measuring unit which obtains 3D information from the dental study model using laser scanning and a personal computer to generate 3D graphics for computed simulation of tooth movements, the representative planes defined by anatomical reference points are formed for each individual tooth and outline of each individual tooth containing the anatomical medial and distal contact points is cut down. Then orthodontic tooth movement is simulated and arranged on representative plane to form an arrangement of 3D profile, when necessary orthognathic surgery can be simulated by moving the mandibular dental arch three dimensionally to establish the optimum occlusal relationship.

Sontoro M et al [40] **2000** evaluated the mesio distal crown dimension and tooth size discrepancy of the permanent dentition of the Dominican Americans. They have shown that the measurement errors in the repeated single operator clinical measurements of plaster casts average 0.2mm.

Demetrios J. Hanzonetis et al [10] **2001**, analyzed the methods of acquisition of three dimensional shapes from images. They have described and selected methods which include stereo analysis, shapes from shadowing, photometric stereo, structured lighting. They state that speed and accuracy are important when choosing appropriate method for acquiring 3D shape of face and teeth. The laser scanning may cause damage to eyes, and it takes 2 hours and 4 minutes to scan one upper model and accuracy is inadequate for scanning dental casts. The cost of scanning a dental cast is about $23,000.

James J. Tomassetti, Louis J. Taloumis et al [20] **2001**, did a comparison of three computerized Bolton tooth size analysis with a commonly used vernier caliper manual method. The mean vernier caliper results were compared with the following computerized methods quick ceph, Hamilton arch tooth system (HATS) and OrthoCAD. In this study to determine examiner reliability, 3 sets of measurements made with vernier caliper were compared using absolute differences. It revealed that 72.7% of the calculations were within 0.9mm of each other. The mean difference was 0.77mm and the range was 0.0mm to 2.4 mm. The quick ceph overall analysis differed from vernier caliper by a mean of 1.84mm. HATS differed from vernier caliper results by 0.3mm to 2.4mm. orthoCAD differed vernier caliper results by 0.0mm to 5.6mm. The author attributed that these deviations are due to less familiarity with the computerized system than with the calipers and difficulty in pinpointing the exact mesial and distal points to be used for the measurement.

Roanld Redmond et al [34] 2001, enlightened the paradigm shift in orthodontic practice management due to advances in computer and digital records. The author advocates 3D digital model and its advantages using orthoCAD software include measurement analysis, midline analysis, overbite and overjet analysis, occlusograms, magnification, anteroposterior and transverse adjustments. The file size of the 3D study model is approximately 3 MB and we can store upto 200 three dimensional study models in one compact disc. He also stated that we can download the models from anywhere in the world within seconds. Orthodontic treatment and interdisciplinary care will benefit from the improved flow and digital patient information.

Sean Curry, Sheldon Baumrind et al [41] 2001, worked on developing practical system for generating integrated three dimensional cranio facial maps by merging information from x-ray cephalograms, study casts and facial photographs. He used radioopaque tie points on the teeth and impressions were taken with poly vinyl siloxane material. Three dimensional digital models were made using Align technology using VOPL/CRIL software the tie points from the model, x-ray and facial photographs were merged together to form three dimensional model. The resulting integrated 3D craniofacial model can be viewed interactively by using Align's TREAT software.

Budi Kusnoto and Carla Evans et al [4] in 2002 had done a study to check the reliability of 3D surface laser scanner for orthodontic applications. In this study accuracy and reproducibility were tested on a geometrically caliberated cylinder, a dental study model, and a plaster facial model taken from alginate impression. All the scanned data were taken in to Sketch Up soft ware (@Last Software, Boulder, Colo) in DXF format to be measured. In this study they have found out that in all cases that the scanner produced more accurate measurements In height (x) and width (y) but less accurate measurements in the depth (Z). For example while measuring intermolar width, the scanner tended to produce smaller value than manual measurements, but produced larger values when measuring palatal depth. The increased accuracy in measuring height and width is due to the unit's horizontal laser beam source. The depth was acquired while the horizontal laser beams moves from top to bottom of the scanned object; time discrepancy occurs between the emitting part of the laser beam to the photosensitive censor while scanning the object's depth; this causes a slight increase in the Z enlargement and the X and Y reduction to get as close as possible to the original dimensions of the scanned object. Therefore they introduced 1.0001 correction factor to reduce the effect of Z enlargement and the X and Y reduction to get as close as possible to the original dimension of the scanned object. While measuring they had a maximum error level 0f 2.4mm and minimum error was 0.1mm – the accuracy is adequate for reconstructing 3D soft tissues. The self correcting mechanism provides greater help in reducing distortion, regardless of object to scanner distance . The spread of the Laser Beam over the object makes the scanner more accurate for smaller objects than for larger objects. Many applications are possible in studying facial soft tissue growth, functional facial muscle movements, dental casts, and arch form changes and head shape.

Choi J.Y.and Kim et al [6] in 2002 analyzed about various errors in medical rapid prototyping of models. They explained that potential errors can occur during CT scan, 3D modeler reconstruction in software, and in RP machine. Errors occurring in CT machine are Pitch and Gantry Tilt, Section thickness, Partial volume averaging effect, Image construction algorithm, Patient movement, and Metal artifact. Errors in 3D modeler are Threshold value, Decimination Ratio, Interpolation algorithm, Smoothing algorithm, Tesselations, Triangular edge. Errors during rapid prototyping are residual polymerization and transformation, Creation and removal of supporting structure, Laser diameter, Laser path, Thickness of Layer, Surface finishing.

Margherita Santoro et al [28] **2003** compared the measurement made on digital and plaster models. Two sets of alginate impressions were taken from patient's mouth, one is asked to make plaster models, and the other impression is scanned to make digital model using OrthoCAD software. There was a statistical significant difference between tooth width and overbite measurement made by the two methods, with all digital model measurements smaller than the corresponding plaster model measurements. But the magnitude of difference does not appear clinically relevant. They concluded that digital models seem to be clinically acceptable alternative to stone cast for the routine measurement used in orthodontic practice. They attributed that the difference may be due to error in operative measurement or incorrective probe angulation.

L. Vrielinck et al [47] **2003** This article presents and validates a planning system for implant insertion based on preoperative CT imaging transferred to Surgicase® software (Materialise,Leveun,Belgium). It allows the surgeon to determine the desired position of different kinds of implants. Finally a customized drill guide is produced by stereolithography. In this study, zygoma, pterygoid and regular platform implants were used. The treatment protocol is validated through 12 case studies, selected at random from the total patient group (*n*=29 patients). From postoperative images, the exact implant location is determined and the deviation of axes between planned and inserted implants is calculated. In this *in vivo* study, displacements, varying according to the type of implant and the location of the implants, were observed. From a clinical standpoint, most of the inserted implants were judged to be adequately sited. A prospective clinical follow-up study was performed on all 29 patients. Although all patients presented with severe maxillary atrophy, excellent cumulative survival rates 92% for the zygoma implants and 93% for regular platform implants have been obtained.

R.Delong, M.Heinzen et al [11] **2003** evaluated the accuracy of a system for creating 3D computer models of dental arches. They made 10 stone casts using Vinyl polysiloxane impression material and improved dental stone. The impressions and stone casts were scanned using Comet-100 optical laser scanner from 20 different views and total time to scan was 20 minutes. Accuracy and precision for the cast and impression was evaluated. They have found that the impression models were nearly twice accurate as the stone models. In this study they concluded that 3D models provided permanent, quantitative record that with accuracy equivalent to the measured occlusal sensitivity of the patients. (Accuracy of cast computer model was 0.024 $\pm$ 0.002mm and that of impression computer model was 0.013 $\pm$ 0.003mm. The difference in value was attributed to a setting expansion of dental stone.

M. Y. Hajeer et al [17] **2004** claimed that the storage of dental casts need a larger space in a hospital, but if the casts are stored in a digital format, after laser scanning or CT, they can be converted into digital format and stored in a CD which requires a smaller space and communication between professionals can be easier.

Federico Cesarani et al [15] **2004** had taken CT's for Egygptian mummies without removing their bandages, and skull and soft tissue reconstruction were done for them. This article laid emphasis on role of the 3D reconstruction of CT, in forensic department.

E Nkenke et al [30] **2004** Fused CT derived virtual skeletal models and optical 3D images of teeth to eliminate scattering due to metal restorations in process of obtaining CT images. This technique gives better detail about the contour of teeth and occlusion and this technique can be used in virtual orthognathic surgery planning.

Meredith L. Quimby et al [29] **in 2004** measured the accuracy and reliability of measurements made on computer-based digital models (Ortho-Cad). In this study a plastic model occlusion i.e., Dentoform, served as a gold standard to evaluate the systematic errors associated with producing either plaster or computer-based models. Accuracy, reproducibility, efficacy, and effectiveness were tested by comparing the measurements of the computer-based models with the measurements of the plaster models—(1) Accuracy: one examiner measuring 10 models made from a Dentoform, twice; (2) Reproducibility and efficacy: two examiners measuring 50 models made from patients, twice; and (3) Effectiveness: 10 examiners measuring 10 models made from patients, twice. Reproducibility (reliability) was tested by using the intraclass correlation coefficient. Repeated measures of analysis of variance for multiple repeated measurements and Student's t test were used to test for validity. Only measurements of maxillary and mandibular space available made on computer-based models differed from the measurements made on the Dentoform gold standard. There was significantly greater variance for measurements made from computer-based models. Reproducibility was high for measurements made on both computer-based and plaster models. In conclusion, measurements made from computer-based models appear to be generally as accurate and reliable as measurements made from plaster models. Efficacy and effectiveness were similar to those of plaster models. Therefore, computer-based models appear to be a clinically acceptable alternative to conventional plaster models.

Hauthuille et al [18] 2005 Compared between computer assisted surgery and surgical planning with rapid prototyping model using MIMICS has been done for distraction osteogenisis and the article claims that the group who were planned with RP model had a better outcome.

Ronald Redmond et al [38] 2006 discussed about internet based treatment planning and communications. He said that one of the basic things we do is to make digital records of patient examination findings, photographs of patients face and dentition, perhaps supplementing these with digital radiographs and models. Dolphin imaging is used to show the patient's and parents the orthodontic problem and the potential treatment solution and even we can give a print out of our initial findings and recommendations for them to take home. Internet communication enterprises (ICE) dental system software allows us to perform all computer based treatment planning and store in ICE server and we can even take copies of our data on DVD. It also provides animation of the proposed treatment; the patient can sign informed consent on screen using digital signature tables. The voice recording capability of the system can be used to record critical conversation with patients and parents.

Daron R.Stevens et al[9] in 2006 studied validity, reliablility and reproducibility of plaster versus digital study models by comparing peer assessment rating and Bolton analysis and their constituent measurements. In this study they have compared standard plaster models with digital counterparts made with e-model software for tooth sizes and occlusal relationships. Measurements were made with digital caliper to nearest 0.01mm from plaster models and with e-software from the digital models. They have concluded that although statistically difference in some measurements were found for the reliability and validity of the digital models via the average of means of absolute differences of repeated measurements none was clinically significant.

Ronald Redmond et al [37] **2006** discussed about the evolution of digital study models. He states that plaster casts served a limited purpose unless they were related to the face. He states that studies comparing digital models with plaster casts have shown that there was no difference in diagnostic accuracy and have concluded that digital models do not compromise orthodontic diagnosis or treatment planning. Cone beam computed tomography (CBCT) has recently enabled 3D visualization of the entire craniofacial complex and virtual study models can be produced from CBCT data. Studies have found no significant differences in orthodontic model analysis between plaster study models and 3D images of the dentition taken from CBCT. Rapid prototyping technologies allow the production of physical models from 3D data. The AAO bulletin reported that courts and juries also have been strongly supportive of digital records for reasons including the ability to back up, search, transport, store and standardize the records.

Pham et al [33] **2007** presented case reports which used recent advances in computer-modeling software that allows reconstruction of facial symmetry in a virtual environment. He evaluated the use of preoperative computer modeling and intraoperative navigation to guide reconstruction of the maxillofacial skeleton. Three patients with traumatic maxillofacial deformities received preoperative, thin-cut axial CT scans. Three-dimensional reconstructions, virtual osteotomies, and bony reductions were performed using MIMICS planning software (Materialise, Ann Arbor, MI). The original and "repaired" virtual datasets were then imported into an intraoperative navigation system and used to guide the surgical repair. Postoperative CT scans and photographs reveal excellent correction of enophthalmos to within 1 mm in patient 1, significant improvement in symmetry of the nasoethmoid complex in patient 2, and reconstruction of the zygomaticomaxillary complex location to within 1 mm in patient.

Computer modeling and intraoperative navigation is a relatively new tool that can assist surgeons with reconstruction of the maxillofacial skeleton.

Andrew P. Keating et al [2] 2008, evaluated the accuracy and reproducibility of three dimensional optic laser scanning device to record the surface detail of plaster study models. Linear measurements were made using hand held digital caliper on thirty randomly selected plaster study models in x,y and z planes. These values were compared with those measured on digital models of the same plaster casts. The mean difference in all planes was 0.14mm and was not statistically different. Subsequently they generated stereolithographic model from digital surface model and the same measurements were made. All z plane reconstructed models were significantly smaller than the corresponding plaster and 3D digital surface model measurements. It was attributed to loss of surface detail particularly of the cervical margin, errors in the data conversion and data manipulation while converting digital surface models to stereolithography file format and errors in RP technique due to model shrinkage during building and post curing. They also have concluded the use of using hand held vernier caliper to measure plaster study models was reliable and reproducible.

Khemachit Sena et al [24] 2008 had used MIMICS Meterialise to evaluate the average measurements of Thai skulls. This was done to produce standardized skull implants for Thai patients. This prevents CT procedure for all the patients as the implants are prefabricated.

Akther Hussain et al [1] 2008, described an alternative imaging of plaster casts with flat bed scanner instead of conventional photography. The perceived advantages of this method are several sets of models can be scanned simultaneously to obtain right and left lateral, frontal and occlusal views. The author recommended scanning resolution of 300dpi for printing. This alternative imaging method eliminates the need for expensive digital cameras, macro lenses, lighting systems and table top setups.

Noortje I. Regensburg et al [32] **2008** evaluated MIMICS (Materialise) as a valuable tool for the calculations of orbital soft tissue volume. Because it can be used on any stack of images, comparisons of CT scans and MRI scans were possible. Intraobserver variability was less than 5% for the calculations of Fat Volume, Muscle Volume, and Bony Orbital Volume. Interobserver variability did improve with better knowledge of anatomy and strict adherence to the segmentation protocol.

Stephan Jacobs et al [44] **2008** described the use of 3D reconstruction in Cardiac surgery. Based on computer tomography (CT) and magnetic resonance imaging (MRI) images, regions of interest were segmented using the MIMICS 9.0 software. The segmented regions were the target volume and structures at risk. After generating an STL-file out of the patient's data set, a 3D plaster model was created. The patient's individual 3D printed RPT-models were used to plan the resection of a left ventricular aneurysm and right ventricular tumor. The surgeon was able to identify risk structures, assess the ideal resection lines and determine the residual shape after a reconstructive procedure (LV remodeling, infiltrating tumor resection). Using a 3D-print of the LV-aneurysm, reshaping of the left ventricle ensuring sufficient LV volume was easily accomplished. The use of the 3D rapid prototyping model (RPT-model) during resection of ventricular aneurysm and malignant cardiac tumors may facilitate the surgical procedure due to better planning and improved orientation.

Ronald Redmond et al [39] **2009,** discussed about securing digital data against computer threats. The author states that malware programs provides unauthorized back door access to the computer and are also used illegally to obtain passwords and encryption keys and they can also change computer settings, resulting in reduced connection speeds, unwanted pop up advertisements and loss of access to the internet and other program. He stresses that in an institution such as dental school, malware can spread rapidly, even to non network computers through the use of flash drives to transfer data. No security software suite can provide total immunity to malware, even if the data base of virus definition is kept up to date. He advises to take up back up of important files regularly.

Timon Mallepree et al [46] in 2009 explained about the technology on which the CT machine, RP(Rapid Prototyping) machine works and about various parameters affecting the accuracy in Digital and reconstructed models. Slice thickness and slice increment are the two important parameters that have to be considered during CT scanning for a proper reconstruction of 3D model in RP. If the space between two slices is too large, information about the real geometry is lost and it results in a poor edge resolution of structures. So the reconstructed model will have a staircase effect due to poor resolution, blurred edges due to partial volume effect and surfaces not well shaped due to noise of an image. Slice thickness is kept at 0.5mm so that there will not be any stair case effect. When these values are kept in optimal values, the accuracy of the RP models is more.

Li WZ et al [26] 2009 provided information about the use of MIMICS a CAD based medical software in surgical treatment of trauma patient. For a Zygomatico-facial collapse deformity resulting from a zygomatico-orbito-maxillary complex (ZOMC) fracture, CT scan data were processed for three-dimensional (3D) reconstruction. The reduction design was aided by 3D virtual imaging and the 3D skull model was reproduced using the RP technique. In line with the design by Mimics, presurgery is performed on the 3D skull model and based on the outcome from the presurgery. Postoperative CT images revealed significantly modified zygomatic collapse and zygomatic arch rise and well-modified facial symmetry. The CAD/CAM and RP technique is a relatively useful tool that can assist surgeons with reconstruction of the maxillofacial skeleton, especially in repairs of ZOMC fracture.

Eldho Markose et al [14] 2009 had conducted experiments on three different materials, acrylic block, dry mandible and goat's head with soft tissue. CT was taken for all the three materials and measurements were done, he checked for accuracy and reproducibility of the measurements in 3D CT, and found that the measurements were accurate and reproducible.

Yoon-Ah Kook et al [49] in 2009 compared the amounts of anatomical overjet measured from facial axis (FA) points with the amounts of bracket overjet measured from bracket slot centre (BSC) points. In this study they have scanned 27 patients with normal occlusion whose models were fabricated in a three dimensional scanner and 3XTer program(Orapix Co Ltd, Seoul Korea) 3D Virtual brackets (0.022" slot, MBT set up, 3M Unitek, Monrvia, Calif) constructed with a 3D –CAD program were placed on FA point with the 3XTer program. The arch dimensions and the amount of overjet from FA and Bsc points were measured. No significant difference in arch width depth was observed between FA and Bsc points. Although the amounts of overjet measured from FA points showed homogenous distribution, a tendency to decrease from anterior segment (2.3mm) to the posterior one (2.0) was noted. However, the amounts of overjet measured from Bsc points were variable, especially in the premolars and molar areas. Significant discrepancies in the amounts of overjet in most of the areas between FA and Bsc points (more than $p<.05$), except the lower second premolar and second molar area were reported even though insets and offsets are part of prescription for the base of straight wire appliance (SWA) brackets. They concluded that the amount of overjet measured from Bsc points were

3mm through the whole segments and that distribution of the amount of overjet from Bsc points was the same as that from FA points were rejected.

Dr.Vishal Dang et al [48] 2009, discussed about the fundamentals of cone beam computerized tomography and stated that CBCT produces high resolution 3D volumetric imaging at high speed scanning with low radiation dose. But he stated that the quality of the image is superior in computed tomography than in CBCT. He also stated that CBCT has poor soft tissue visualization. He stated that routine CBCT study in orthodontics delivering an effective dose of 61.1 μSv compared with 429.7 μSv for multisection computed tomography. Lateral cephalograms deliver 10.4 μSv in comparison, thought without the benefit of 3D structural visualization.

Dong Soon Choi et al [11] in 2010 evaluated the accuracy of superimposition of 3D digital models using the palatal surface as a reference for measuring tooth movements. In this study they have used Orapix 3D laser scanner accuracy of + 20 micro meter for scanning the models and 3D reverse modeling software program-Rapidform to measure the models. They have used first, second and third palatal rugae for superimposition. Van der Linden evaluated the changes in rugae and inter rugal dimensions in 65 normally growing children and in 6 orthodontically treated patients. The authors noted little or no change in the length of individual rugae and inter rugae distances. Results in the study suggest that superimposition of 3D digital models using surface to surface matching technology in the palatal area can result in accurate and reliable measurements for assessment of orthodontic tooth movements. The present study investigated the accuracy of the best fit method when identical palatal surfaces were scanned twice and superimposed. Whether similar accuracy can be achieved when repeated impressions made in growing patients remains to be determined.

Sridevi Padmanabhan et al [43] 2010 concluded that CT measurements did not show a significant difference from the direct skull measurements (P , 0.05) in all three planes except for two midsagittal measurements in the anteroposterior plane. Cephalometric measurements were comparable to direct skull measurements for midsagittal measurements in the anteroposterior plane, but showed a significant difference when bilateral measurements were considered. Cephalometric measurements also showed a significant difference in the transverse plane from direct measurements and CT measurements; however, they did not display a significant difference between direct skull measurements and CT measurements for most parameters in the vertical plane. Linear measurements on the spiral CT were comparable to anatomical measurements and were more reliable than cephalometric measurements. Cephalometric measurements were acceptable for midsagittal measurements in the anteroposterior plane, but showed a significant variation from anatomical and CT measurements in most other parameters.

Chung How Kau, Jay Little Field, Neal Rainy et al [7] in 2010 evaluated the use of CBCT Digital models by comparing it with traditional OrthoCAD generated models. In this study the imaging device they have used was Sirona Galileos (Bensheim, Germany). The Galileos X-Ray detector receives cone shaped cone-beam radiation beams, which results in 200 individual exposures from a 14 second cycle in a 200 segment. Volume dimensions of 15X15X15 cm cube capture an image at high level of detail. The technology also allows for small region close up views at double the detail without an additional scan. The large dental volume ranges from bridge of the nose to the tip of the chin and the mandibular joints. It protects the bone structures with the same reliability as the soft tissue. The voxel size is between 0.15mm and 0.30mm. The image reconstruction time was approximately 4.5minutes. CBCT images were electronically sent via a secure website to the company Anatomage in a Dicom format. These files were converted to volume rendering software, and a final 3D-generated model of teeth was produced and analysis made on proprietary software package. Alginate impression were taken and sent to OrthoCAD for digital conversion. The scans were then taken electronically returned in Digital format for analysis. Littles irregularity index was used to measure distances between teeth. Measurements were made by measuring the linear displacement of the anatomical contact points between the anterior six teeth on the maxilla and mandible in the horizontal occlusal plane. The results from this study showed that digital models generated from CBCT imaging not only offer diagnostic information but also other information such as bone levels, root resorption and TMJ status are also captured. They are not present on OrthoCAD models. Orthodontists can also eliminate the use of dental impression for diagnostic casts. The idea of gathering all diagnostic records from a single CBCT scan is most intriguing to the orthodontic profession. As computer technology improves, the occlusal distortion in the CBCT models should also improve with constantly improving CBCT technology, the ability to gather all diagnostic records from a single CBCT scan seems imminent. Future research needs to be conducted for surface shape and volumes of CBCT images. They have concluded CBCT digital models are as accurate as OrthoCAD digital models in making linear measurements for overjet, overbite and crowding measurements.

Bootvong, Z.Liu et al [3] in 2010 studied virtual model analysis as an alternative approach to plaster model analysis. He compared virtual dental models obtained from OrthoCAD and corresponding plaster models of 80 patients in permanent dentition were randomly selected from patients seeking orthodontic care. Inter examiner error was assessed by measuring tooth width, overjet, overbite, intermolar width, intercanine width and mid line discrepancy. Both intra and inter examiner reliability and test –retest reliability of virtual model analysis were acceptable in measuring the above mentioned parameters. There were substantial agreements for canine and molar relationship classifications. The results suggest that analysis performed on virtual models was a valid as traditional plaster models for intra and inter arch relationship.

Daniel S .German and Julia German[8] in 2010 had overviewed about the uses of CBCT in orthodontics. CBCT has an advantage over normal CT as its radiation exposure is only 20% of that from CT. The required data is acquired in one minute, technician positions the patient in the same way as for panoramic or cephalogram imaging. More than 30 different machines are available. Using CBCT obtained images a third party software such as Anatomage allows digital reconstruction of dental casts, trimmed according to ABO (American Board of Orthodontics) standards. An additional benefit of these views is the ability to evaluate the roots and some of the alveolar structure. The occlusion in the digital models is identical to that displayed in the saggital TMJ view and the cephalometric images.

Materials and Methods

MATERIALS AND METHODS

Fifteen pairs of randomly selected plaster study models from the orthodontic department of Ragas Dental College, Chennai, were used in the study. Each plaster study model was made of OrthoKal® (Registered trade mark of Kalabhai, orthodontic stone class III), with proportional bases, made from same base former (Leone®) (Fig.1).

INCLUSION CRITERIA:

The inclusion criteria were:

I. The plaster study models should completely reproduce the arch.
II. All the teeth should be in permanent dentition.
III. Mesial cusp of the upper and lower second molar should be erupted.
IV. No missing teeth or no existing orthodontic appliance.
V. The models can have varying degrees of contact points and bucco-lingual displacements.
VI. The models should not show any surface marks, loss of tooth material, voids or fractures.

MANUAL MEASUREMENTS

Hand held Digital Vernier Caliper (Aero Space) (Fig 5) was used in the study to manually measure the plaster models by two examiners on two different occasions. This caliper had measurement resolution of $\pm$0.02mm/0.001”in 0-100mm range and the data were recorded manually. All plaster models were measured in a bright room without magnification. The plaster models were not prepared in anyway prior to measuring and anatomical landmarks used in the measurement were not pre marked. Two examiners independently conducted all the measurements after an initial training period. Twenty linear dimensions were measured on each model in each of three planes (X, Y, Z) with all measurements recorded to the nearest of 0.01mm. (Fig 4)

The following dimensions were selected for measurement:

X PLANE:

1. Intercanine distance - measured at the distance between:
   - (i) The occlusal tips of upper canines;
   - (ii) The occlusal tips of lower canines.
2. Interpremolar distances - measured as the distance between:
   - (i) The buccal cusp tips of the upper and lower first and second premolars;
   - (ii) The palatal cusp tips of the upper first and second premolars;
   - (iii) The lingual cusp tips of the lower first premolars;
   - (iv) The mesiolingual cusp tips of the lower second premolars.
3. Intermolar distances- measured as the distance between:
   - (i) The mesiopalatal cusp tips of upper first and second molars;
   - (ii) The mesiobuccal cusp tips of upper and lower first and second molars;
   - (iii) The mesiolingual cusp tips of lower first and second molars;
   - (iv) The disto-buccal cusp tips of the upper and lower first molars.

Y PLANE:

1. On both sides of the upper arch the distance from the mesiopalatal cusp tip of the upper second molar to:
   (i) The mesiopalatal cusp tip of the upper first molar;
   (ii) The palatal cusp tip of the upper first and second premolar;
   (iii) The cusp tip of the upper canine;
   (iv) The mesio-incisal corner of the upper lateral incisor were measured.
2. On both sides of the lower arch the distance from the mesiolingual cusp tip of the lower second molar to:
   (i) The mesiolingual cusp tip of lower first molar and second premolar;
   (ii) The lingual cusp tip of lower first premolar;
   (iii) The cusp tip of lower canine;
   (iv) The mesio-incisal corner of the lower lateral incisor were measured.

Z PLANE:

The clinical crown height of all the teeth, in both upper and lower arches, from second premolar to second premolar inclusive, measured as the distance between the cusp tip and the maximum point of concavity of the gingival margin on the labial surface.

VIRTUAL MEASUREMENTS

A 3D computed tomography scanner (Siemens SOMATOM Sensation 64 Slice) was used to record the 3D detail of each of the 15 pairs of study models in single scan with high resolution sinus algorithm (slice thickness, 0.50mm: 120kv and 225 and 250mA (anterio-posterior-latero lateral), H70h). The CT images were saved in standard Digital Imaging for Communication in Medicine (DICOM) format in a compact disc (CD).

The CT data are imported in to Computer Aided Designing (CAD)-based medical software, Materialize Interactive Medical Image Control System (MIMICS-MATERIALISE-BELGIUM) for multiplanar reconstruction. All the measurements are done in software.

Protocols during CT scan:

15 pairs of dental models were placed on the scanner bed (Fig 2) with a cardboard underneath the models, as the scanner bed was not flat. The models were placed in upright position. This position was selected because more number of models could be placed in single exposure. Models were placed in columns with the arches facing each other (Fig 3). Adequate space was maintained between the models such that the images would not overlap. To identify the models, a lead alphabet was placed next to it. The images were taken in the sharpest algorithm in the CT machine (sinus algorithm, slice thickness, 0.50mm: 120kv and 225 and 250mA (anterio-posterior-latero lateral, H70h). Each row data was stored in a separate CD in DICOM format. Each CD was labeled according to model number.

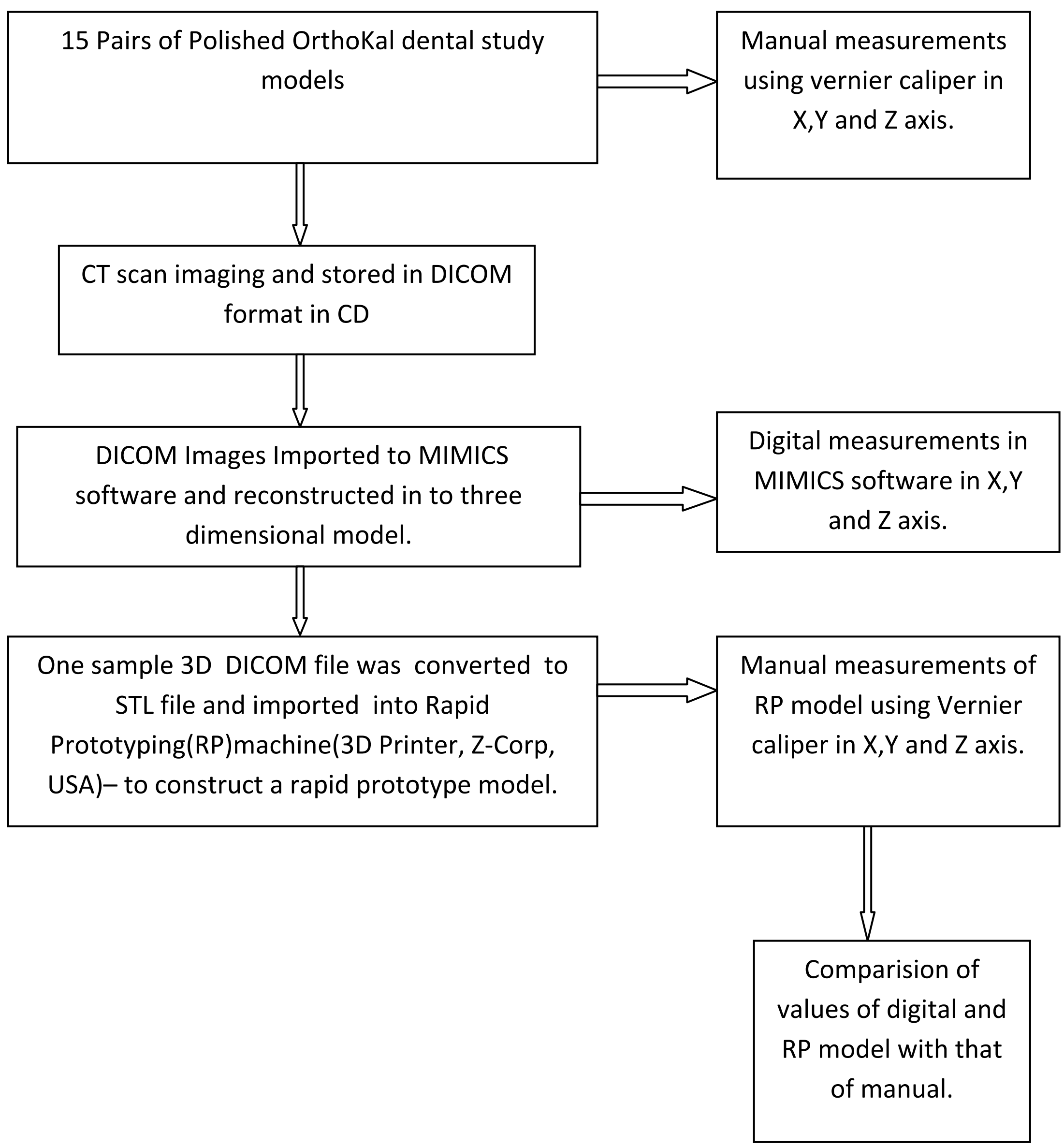
Protocols and Measuring Technique in MIMICS Software:

Computed tomography data were imported into MIMICS software. The software reconstructed the data into three dimensional (3D) digital models. Each study model can be given different colours for identification. The 3D reconstructed models can be rotated and also magnified using the software (MIMICS) which aids us in taking accurate measurements. All X and Y axis measurements were taken in occlusal view and Z axis measurement were taken in frontal, right and left views. For measuring the distances between teeth, a built in tool (measure 3D distance tool) was selected and just by clicking and dragging on the selected points, the measurement between the points was (Fig 10,11) obtained. While measuring the Z axis (clinical crown height) of each tooth, the model can be given “transparency view” by clicking an in built transparency tool, since the cervical margin of tooth was more clear in that view (Fig 12a,b) All the measurements were noted down. The measurements were repeated by another operator at a different time.

MEASUREMENTS OF RECONSTRUCTED MODELS:

One sample of 3D data was selected and Rapid prototyping model was prepared. For this purpose the DICOM data in the computer was imported to MIMICS software in which the DICOM data was converted into “Virtual Object”. This virtual object can be exported as STL (Standard Triangulation Language) file. This file was sent to the Rapid prototyping (RP) manufacturing unit. The rapid prototyping machine (3D printer Z corp.) converted the STL file into Composite physical model (Composite powder and binder) (Fig 13). Measurements were carried out on the Rapid prototyping model using vernier caliper and the values were compared with that of the manual and digital measurements (Fig 14, 15). This was a pilot study done on only one sample and further studies can be carried out using different prototype materials.

FLOW CHART OF STUDY



Figures

Fig. 1 : 15 pairs of plaster study models used in the study

Fig. 2 : Models positioned in 3D CT Scanner

Fig. 3 : Close view of the model arrangement in 3D CT Scanner

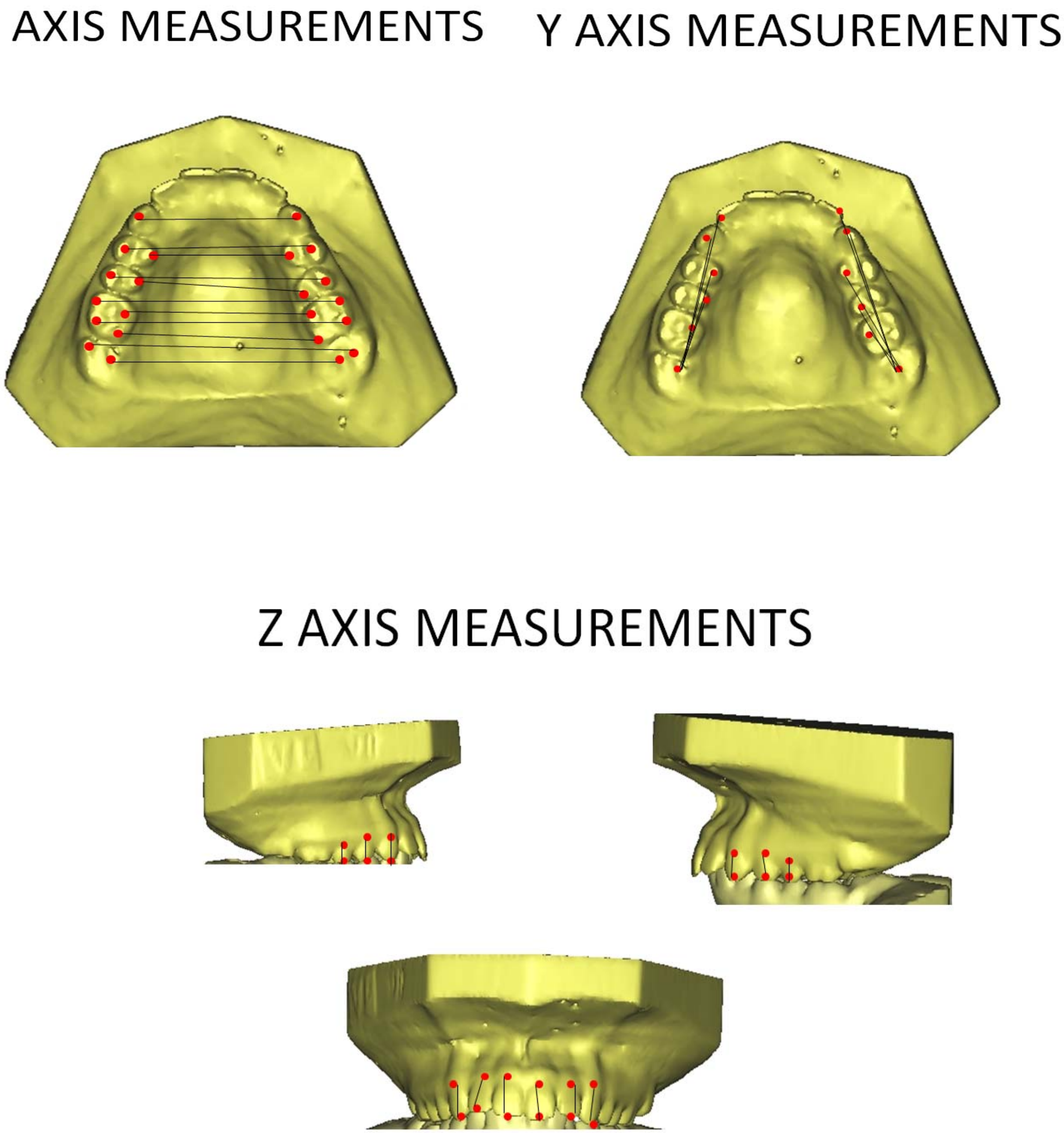


Fig. 4 : Pictures showing measurements taken in X, Y and Z axis

Manual Measurements of Plaster Study Model

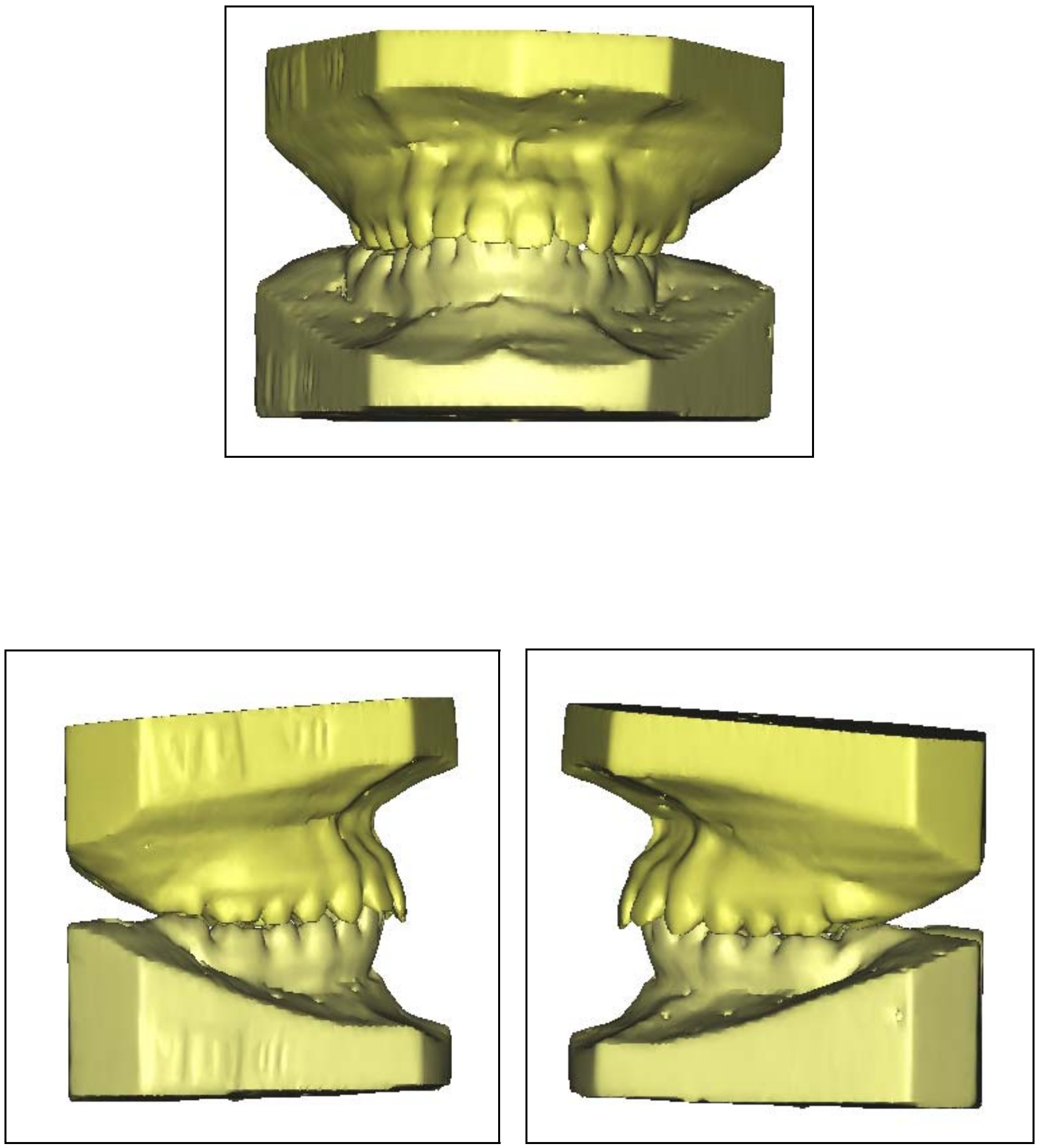
Fig. 5 : Aerospace Vernier Caliper

Fig. 6 : X axis – intercanine measurement

Fig. 7 : Y – axis measurement from mesiopalatal cusp tip of upper second molar to mesiopalatal cusp tip of upper first molar

Fig. 8 : Z – axis measurement clinical crown height of upper right second premolar

Fig. 9 : Digital Models reconstructed using MIMICS software



Digital Model Measurements

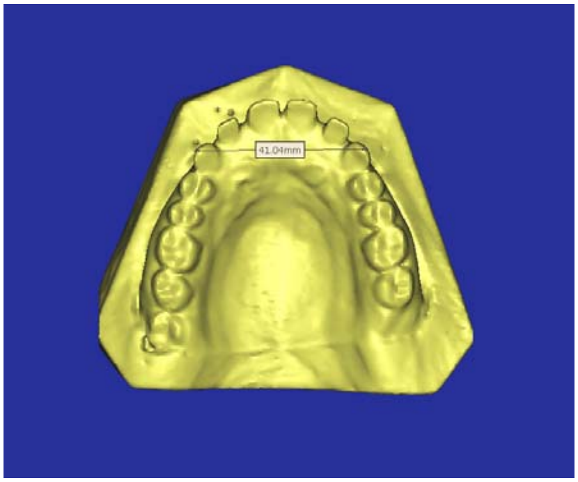


Fig.10 : X – axis intercanine measurement

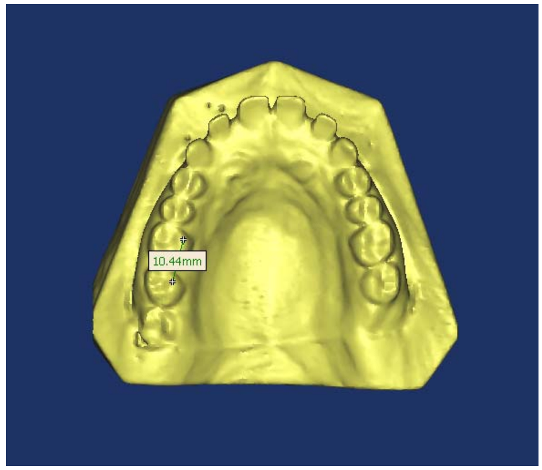


Fig. 11 : Y – axis measurement from mesiopalatal cusp tip of upper second molar to mesiopalatal cusp tip of upper first molar

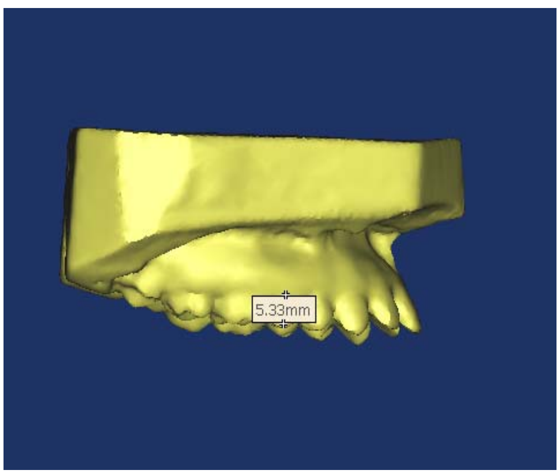


Fig. 12a Z – axis measurement clinical crown height of upper right second premolar

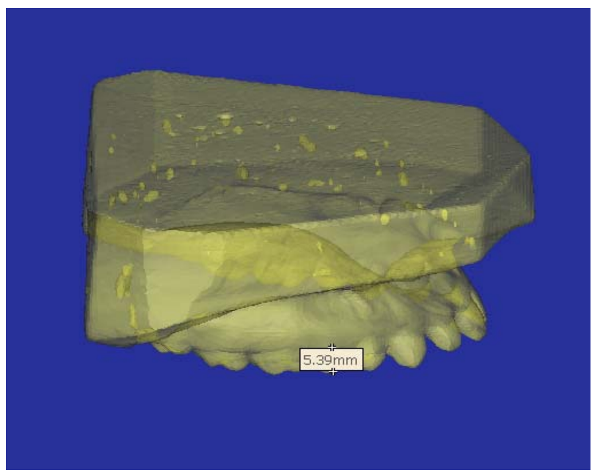


Fig. 12b :Z – axis measurement clinical crown height of upper right second premolar with transparency

Fig. 13 : Composite Prototype models

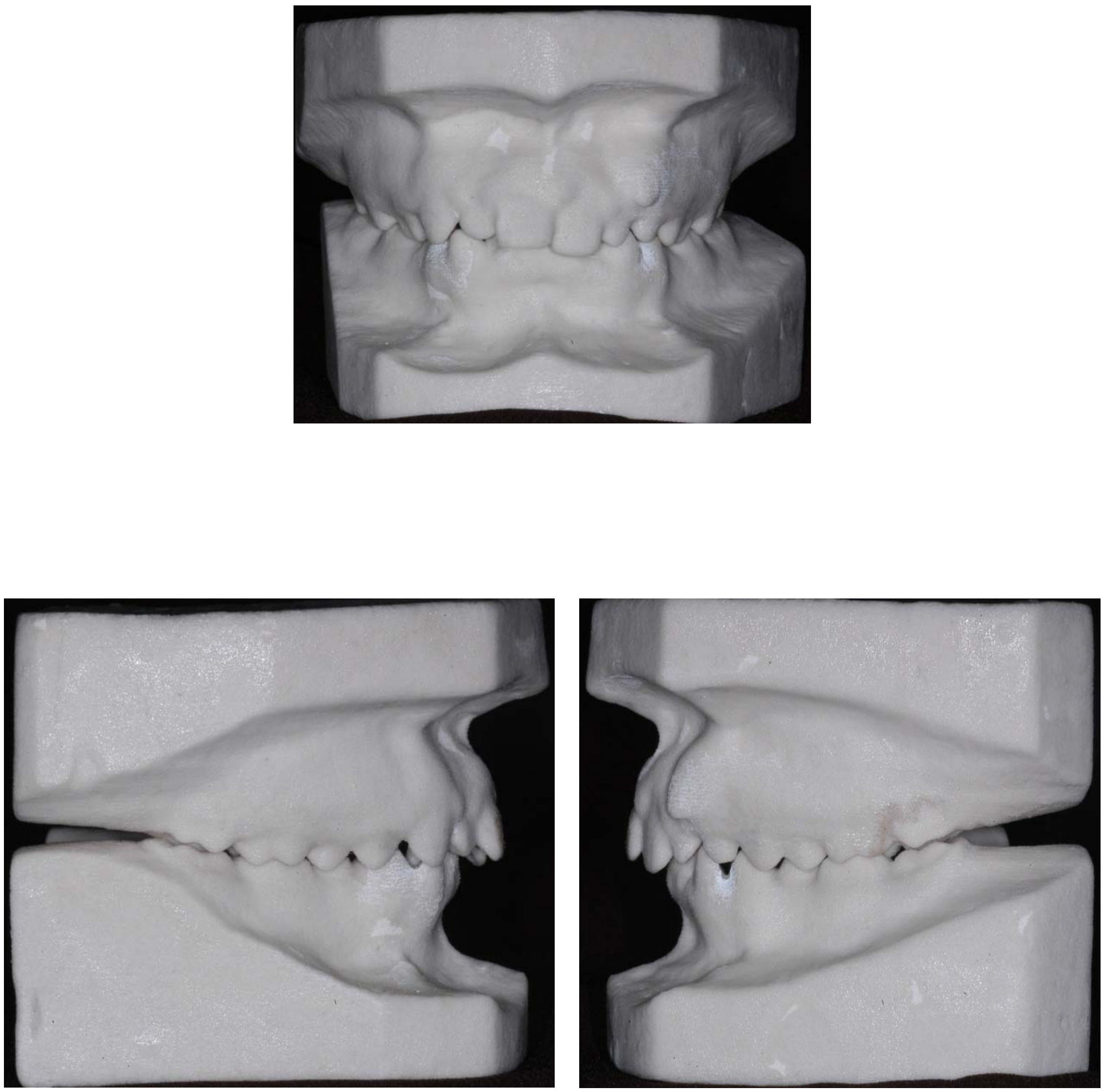
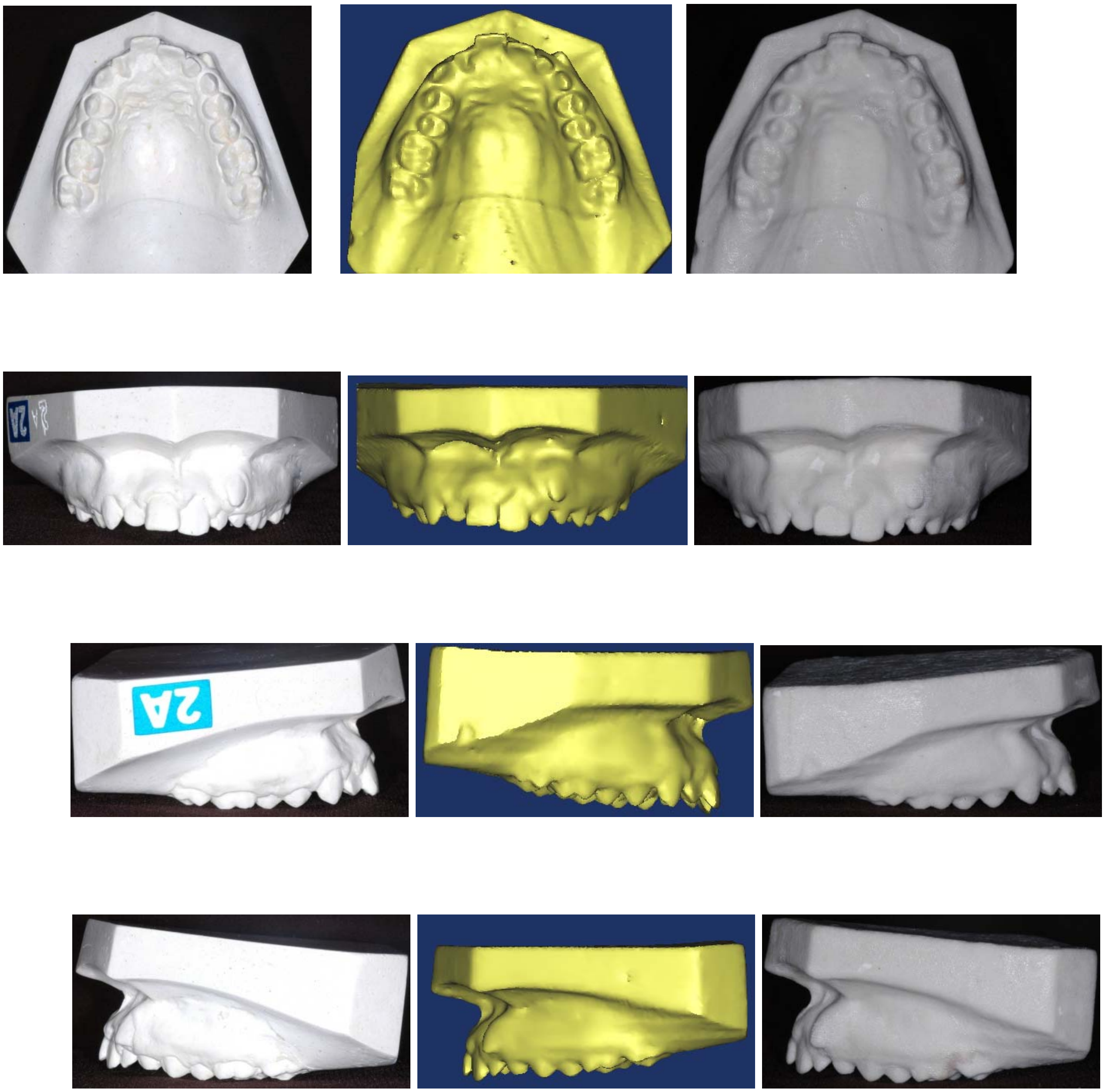


Fig. 14 : Comparison of Plaster, Digital and Reconstructed upper study model

a b c

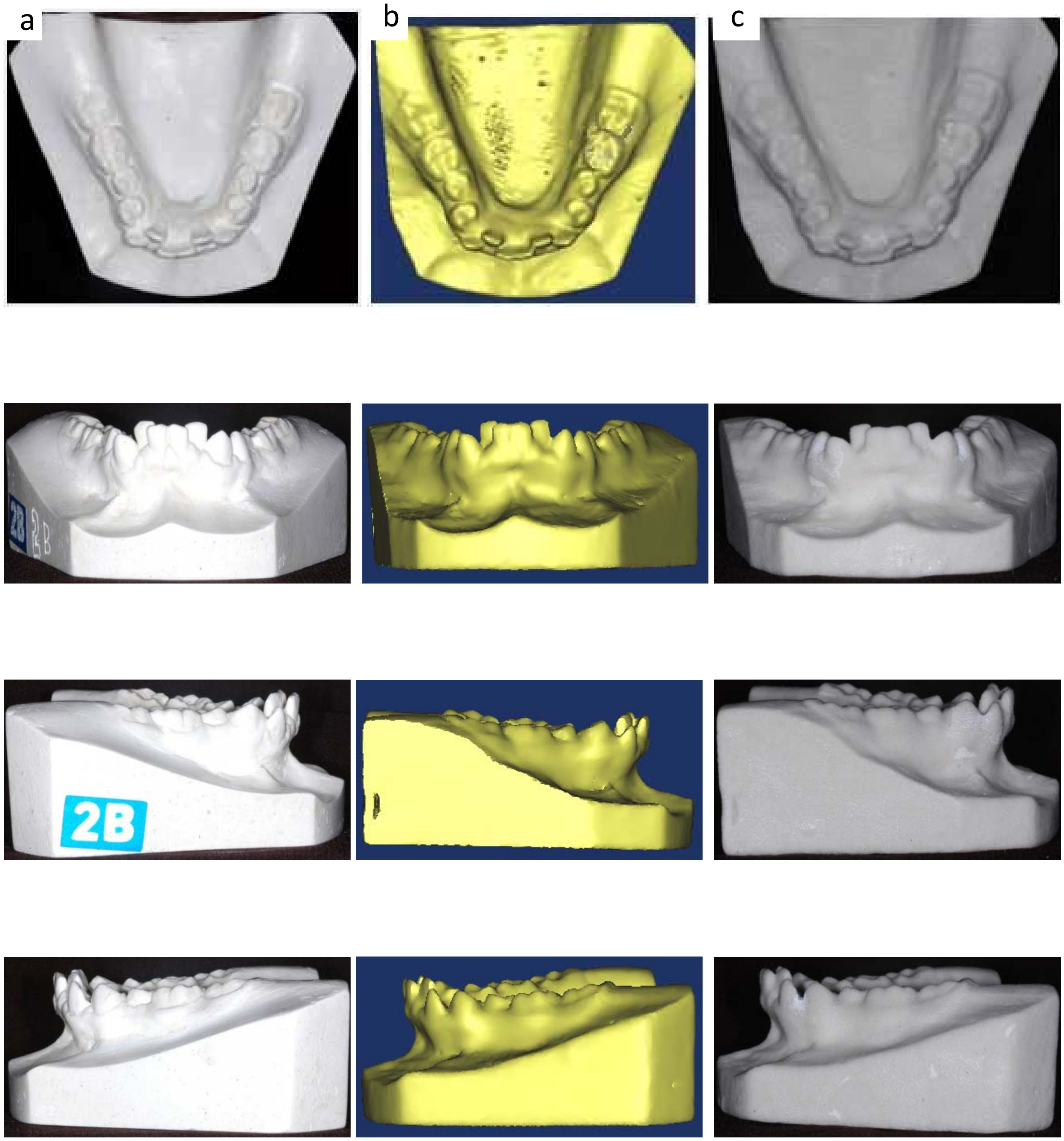


a – Plaster Model

b – Digital Model

c –Reconstructed Study Model

Fig. 15 : Comparison of Plaster, Digital and Reconstructed lower study model



a – Plaster Model

b – Digital Model

c –Reconstructed Study Model

Results

RESULTS

Data analysis in our study demonstrated a non-normal distribution of results; therefore non parametric tests were employed in the statistical analysis. A **Wilcoxon signed rank test** was undertaken to determine agreement between repeat model measurements and inter rater reliability. The same above test was used to determine the significance of difference between the plaster, digital and reconstructed models.

Manual measurements were made with vernier caliper on plaster dental casts and reconstructed model in this study. To establish this method as a reliable and consistent way to measure the linear variables in the X, Y and Z axis, the measurements were done by two different operators at two different time points in all the 15 pairs of plaster study models and one pair of reconstructed model. The linear measurements in the digital model were done by measuring tools in the MIMICS software, by two different operators measured at two different time points in all the 15 pairs of digital casts.

The data obtained with plaster model, digital model and reconstructed models were stored in computer and presented as an excel page. A statistical package **SPSS (SPSS 16.0 version, Chicago, ILLINOIS, USA)** was used to analyse the comparison. The differences were compared using **Wilcoxon signed rank test.** P value less than 0.05 was considered statistically significant.

The mean absolute difference in repeat measurements of plaster models in X, Y, Z planes were 0.19mm ($p = 0.067$) , 0.23mm ($p = 0.083$), 0.03mm ($p = 0.128$) respectively. The overall mean absolute difference was 0.15 mm. The P value was 0.099 which indicated that there was no statistically significant difference between the repeat measurements in plaster model. It is shown in Table 1. and Graph 1.

The mean absolute difference in repeat measurements of digital models in X, Y, Z planes were 0.19mm ($p = 0.296$), 0.15mm ($p = 0.073$), 0.07mm ($p = 0.351$) respectively. The overall mean absolute difference is 0.14 mm. The P value was 0.124 which indicates that there was no statistically significant difference between the repeat measurements in digital model. The values are displayed in Table 2.and Graph 2.

The mean absolute difference in repeat measurements of reconstructed model in X, Y, Z planes were 0.27mm ($p = 0.211$), 0.95mm ($p = 0.062$) , 0.31mm ($p = 0.211$) respectively. The overall mean absolute difference was 0.51 mm. The P value was 0.189. These values established that there was no statistically significant difference between the repeat measurements in reconstructed model. It is depicted in Table 3. and Graph 3.

When plaster models and digital models were compared there was no statistically significant difference in the X, Y and Z plane. The mean difference in the X, Y and Z plane were 0.17mm ($P = 0.225$), 0.16mm ($p = 0.083$) and 0.08mm ($p = 0.279$) respectively. The overall mean absolute difference was 0.14mm and p value was 0.114. The results showed that there was no statistically significant difference between plaster and digital in all three dimensions. It is given in table 4 and Graph 4.

The comparison between plaster and reconstructed model showed that statistically significant difference was found between plaster and reconstructed model. The mean difference in X, Y, and Z planes were 3.39mm ($p = 0.044$), 1.32mm ($p < 0.001$), 0.70mm ($p = 0.007$) respectively. The overall mean absolute difference in all three planes was 1.80mm and the P value is less than 0.001. It showed that statistically significant difference was found in all three planes between plaster and reconstructed model. The values are shown in table 5 and Graph 5.

Finally, the difference between digital and reconstructed model showed that there was significant difference were found in Y and Z planes. The mean difference in X plane was 3.47 ($p = 0.093$) and in Y, Z planes were 1.32mm ($p = 0.002$) and 0.69mm ($p = 0.037$) respectively. The overall absolute difference in X, Y, Z plane was 1.83mm. The P value was 0.011. These values showed that the difference between digital and reconstructed model was statistically significant in Y, Z planes and it was not statistically significant in X plane. The results are displayed in Table 6 and Graph 6.

Tables & Graphs

Table 1. Variation in repeat measurements of plaster model - 20 measurements in each plane repeated on 15 models

Plane	N	Mean	Std. Dev	P - value
X - Plane	20	0.185	0.200	0.067
Y - Plane	20	0.227	0.162	0.083
Z - Plane	20	0.025	0.027	0.128
X, Y, Z - Planes	60	0.146	0.1716	0.099

Graph 1.

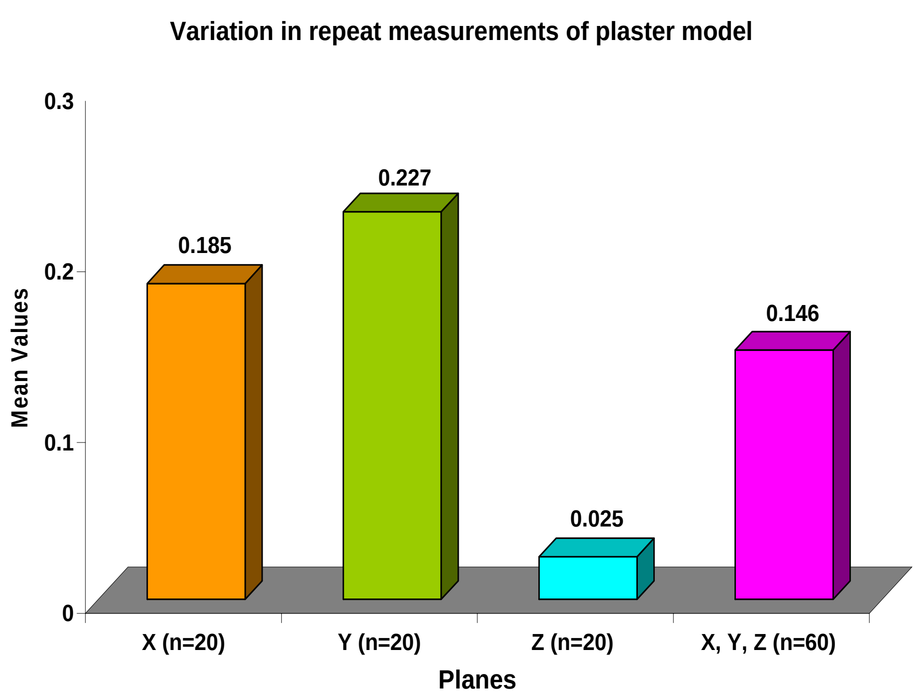


Table 2. Variation in repeat measurements of digital model - 20 measurements in each plane repeated on 15 models

Plane	N	Mean	Std. Dev	P - value
X - Plane	20	0.188	0.379	0.296
Y - Plane	20	0.148	0.124	0.073
Z - Plane	20	0.068	0.052	0.351
X, Y, Z - Planes	60	0.135	0.234	0.124

Graph 2.

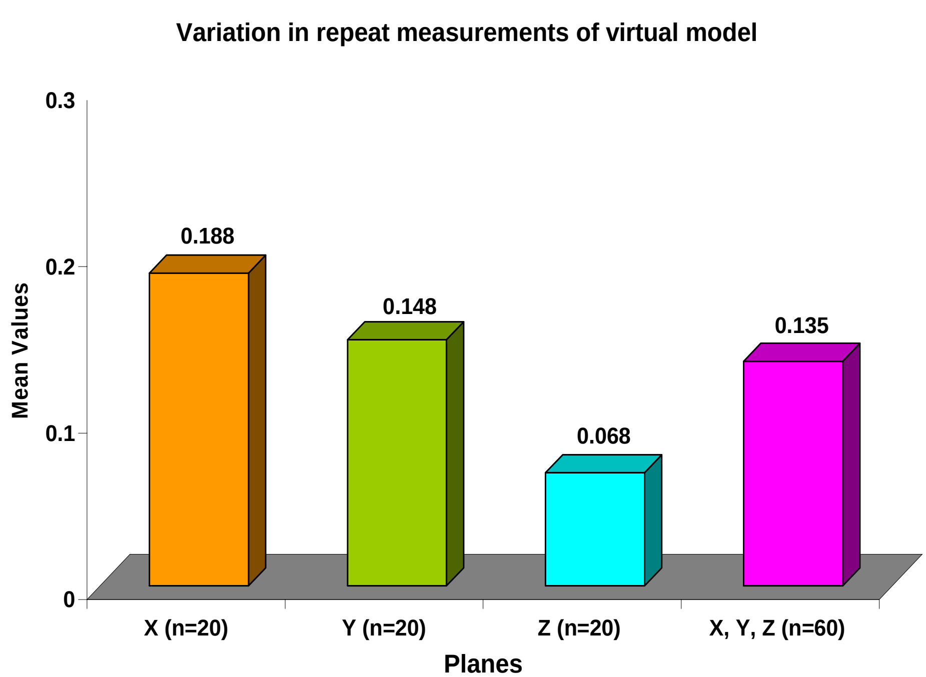


Table 3. Variation in repeat measurements of reconstructed model - 20 measurements in each plane repeated on one model

Plane	N	Mean	Std. Dev	P - value
X - Plane	20	0.273	0.168	0.211
Y - Plane	20	0.950	1.620	0.062
Z – Plane	20	0.312	0.296	0.211
X, Y, Z - Planes	60	0.512	0.990	0.189

Graph 3.

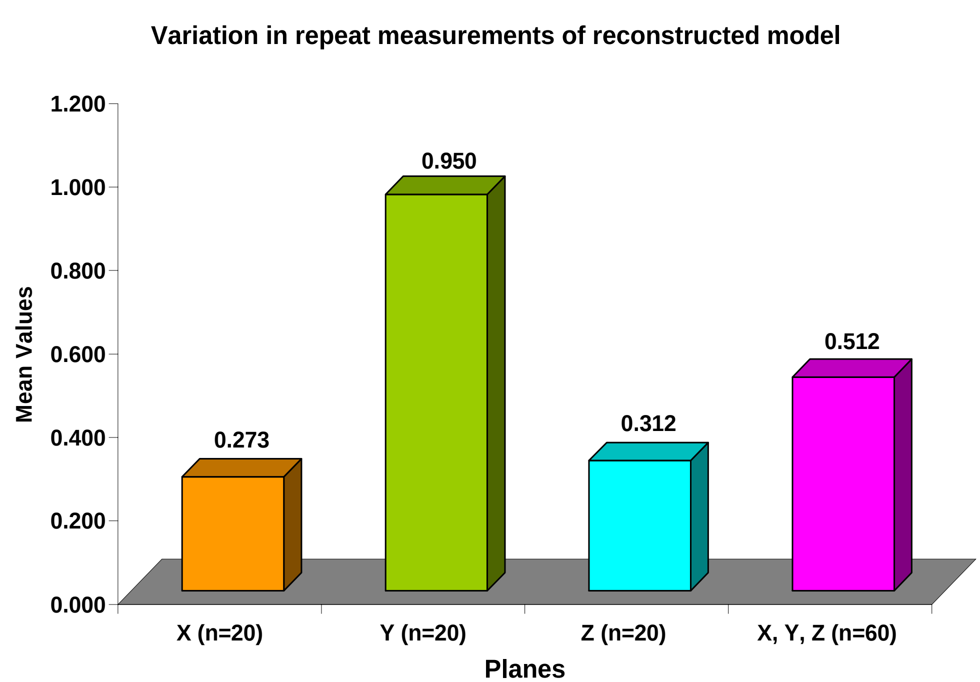


Table 4. Difference between plaster and digital model measurements means of 20 measurements in each plane compared

Plane	N	Mean	Std. Dev	P - value
X - Plane	20	0.173	0.234	0.225
Y - Plane	20	0.163	0.161	0.083
Z - Plane	20	0.077	0.047	0.279
X, Y, Z - Planes	60	0.138	0.178	0.114

Graph 4.

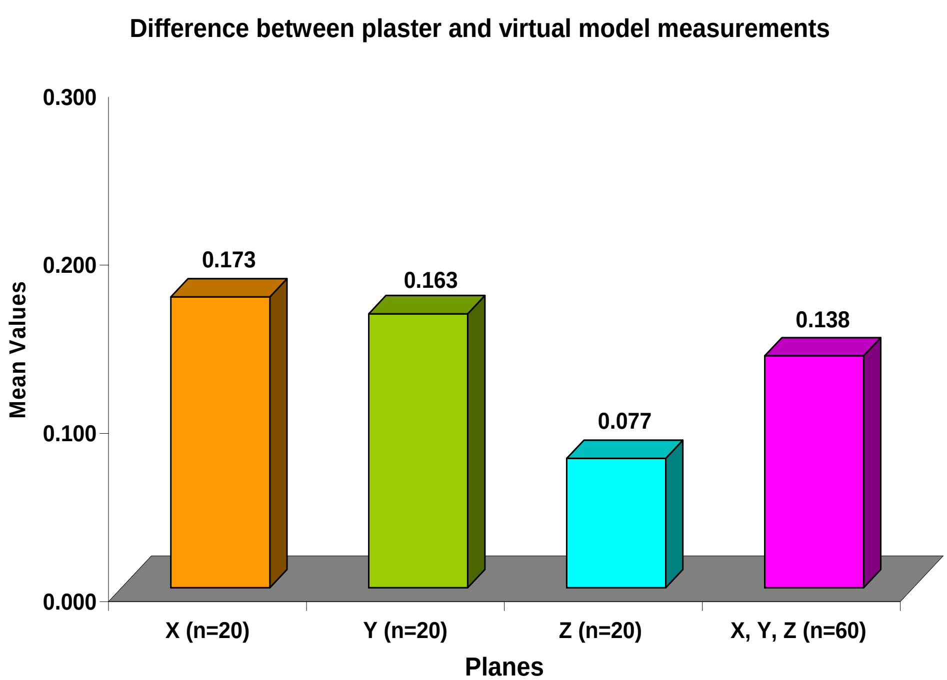


Table 5. Difference between plaster and reconstructed model measurements means of 20 measurements in each plane compared

Plane	N	Mean	Std. Dev	P - value
X - Plane	20	3.390	3.829	0.044
Y - Plane	20	1.318	1.120	<0.001
Z – Plane	20	0.701	0.601	0.007
X, Y, Z - Planes	60	1.803	2.567	0.001

Graph 5.

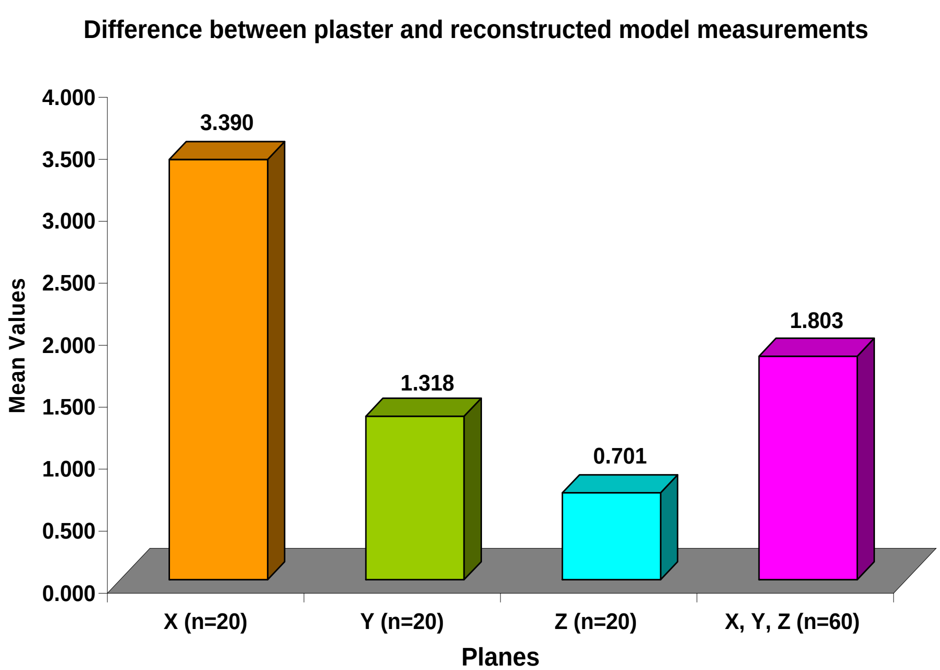
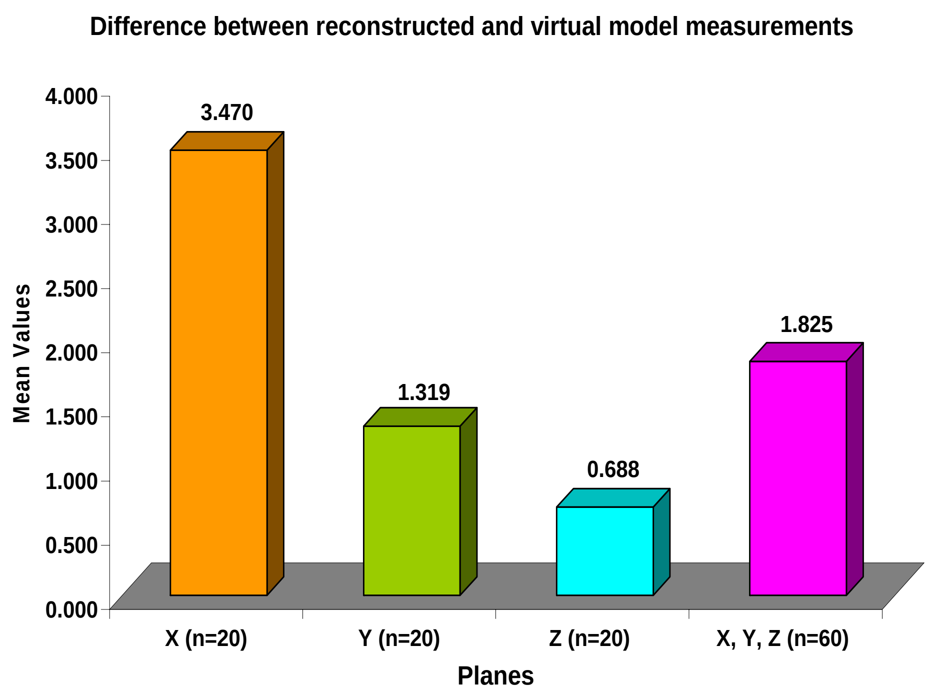


Table 6. Difference between digital and reconstructed model measurements means of 20 measurements in each plane compared

Plane	N	Mean	Std. Dev	P - value
X - Plane	20	3.470	3.724	0.093
Y - Plane	20	1.319	1.196	0.002
Z - Plane	20	0.688	0.595	0.037
X, Y, Z - Planes	60	1.825	2.546	0.011

Graph 6.



Discussion

DISCUSSION

Traditional study models provide an accurate representation of the malocclusion and have been economical to produce. Hajeer et al[16] claims that the storage of dental casts need a larger space in a hospital, but if the casts are stored in a digital format after laser scanning requires a smaller space and communication between professionals made easier.

Various methods of acquisition of three dimensional images of dental casts were found in the literature. An **early** version involved taking photographs of the plaster casts, digital scanning, holograms, stereophotogrammetry and laser scanning. Halozonetis et al[10], analyzed the various methods of acquisition of three dimensional shapes from images which included stereo analysis, shapes from shadowing, photometric stereo, structured lighting. They stated that speed and accuracy are important when choosing appropriate method for acquiring three dimensional (3D) shape of face and teeth.

In 1990, Quick Ceph Software Company used photographs of plaster casts taken in five different orientations for digital storage[37]. In 1996, Kuroda et al[45] used laser scanning to create three dimensional study model. In 1997, Schrimer et al[42] photostat the models and digitized to measure the mesiodoistal width. In 1998, Mok et al [23] used Sonic digitization to analyze space analysis. In late 1999, OrthoCAD (CADDENT, Carlstadt, NJ) developed virtual digital dental cast. In early 2001, emodels (GeoDigm, Chanhassen, Minn) came to the market. In 2001, Halozonetis et al[9] analysed the use of laser scan for dental models. In 2008, Akther et al[1] scan the models on flat bed scanner in four different views for digital storage purpose. In 2010, German et al[8] had constructed digital models from Cone Beam Computed Tomography (CBCT) scan by using software “Anatomage” according to ABO (American Board of Orthodontics) standards.

Photocopies[17] are easy to handle, but manually measuring teeth with a calibrated gauge produces the most accurate, reliable and reproducible measurements than photocopies. Akther[1] described an alternative imaging of plaster casts with flatbed scanner instead of conventional photography. It aids in digitizing the models and storage. The perceived advantages of this method are several sets of models can be scanned simultaneously to obtain right and left lateral, frontal and occlusal views. But it gives two dimensional pictures of three dimensional dental models. Accurate measurements are not possible on these scanned models due to convex structure of teeth, curve of Spee, tooth inclination, and tooth position.[40]

By the mid 1990s digital scanning technology was developed using laser surface scanner to create three dimensional dental models. Disadvantage of this system is the impossibility of the sampling beneath the overhangs and also parallax angle between laser emitter and receiver causes blind region around deep grooves with an overhang[45]. The laser scanning may cause damage to eyes, takes longer time to scan one model and the accuracy was inadequate for scanning dental casts. The cost of scanning a single dental cast is about $23,000 [10]

The **aim** of our study is to compare the accuracy of plaster, digital and reconstructed study model using Spiral Computed Tomography (CT) scan.

Markose et al[14] 2009 assessed the accuracy and reproducibility of measurement in three different kind of materials (acrylic block, dry mandible and Goat’s head) in 3D CT using MIMICS software and found that the measurements were accurate and reproducible. Sridevi et al[43] compared the linear measurement made on dry skull with that of CT scan using MIMICS software. They found that digital image measurements were comparable to anatomical measurements and were more reliable. So in **our study** we have used spiral computed tomography data and MIMICS soft ware for producing and measuring digital dental model.

Spiral CT (also referred as helical or volume acquisition CT) involves simultaneous translator movement of the object while the X-ray source rotates so that continuous data acquisition is achieved while scanning the entire volume of interest. The spiral CT scanner provides adequate data to create 3D image with reduced radiation and scanning time because of the continuous scanner, and rotation with table top movement. All 15 pairs of dental models were arranged in an orderly fashion and were scanned using spiral computed tomography in a single exposure. The entire models were scanned within one minute when compared to Laser scan which takes 40 minutes[10] to 2 hours depending on the size and volume of the each cast.

Though there are various softwares available for measuring digital models like HATS (Hamilton Arch Tooth Systems), OrthoCAD, and Quickceph, MIMICS is the standard software for 3D image processing and editing based on scanned data. The software can translate multitude image modalities including CT, MRI and Micro CT into complete 3D model very easily and quickly. It can process any number of 2D image slices. It has powerful automatic and manual segmentation tools for grey value images.[14,18,24,26,32,33,43,44]

Traditionally, a Boley gauge, Vernier caliper, or needlepoint divider is used to measure teeth and complete a tooth size analysis. In **our study** Vernier caliper was used to measure the manual measurements in plaster and reconstructed model. Inter rater reliability of measurement for plaster model with vernier caliper in X, Y and Z planes were reliable and accurate and difference is statistically insignificant (p=0.099). Repeat measurement of reconstructed model using Vernier caliper was also statistically insignificant (p= 0.189). The results were in agreement with Keating et al,[2] Mok et al,[23] Santoro et al,[28] Tomasetti et al,[20] Stevens et al[9] and Qumbi et al[29]. These studies showed good reliability of using vernier caliper for linear measurements.

The repeat measurement in digital model using digital tools of MIMICS software was accurate in all three axis (p = 0.124). This showed good agreement between repeat measurements of digital model using MIMICS software. This is in agreement of digital model measurement repeatability of Keating et al[2] for repeatability of surface laser scan models, Quimby et al[29] and Santoro et al [28] for repeatability of orthoCAD model measurement, Stevens et al[9] for repeatability of emodels, Mok et al[23] for repeatability of Digigraph workstation.

In **our study**, the mean absolute difference between plaster and digital models showed good agreement and reliability, the differences were statistically insignificant in X, Y and Z planes (p = 0.114). There is no difference in dimensional accuracy of 3D digital surface models captured with CT scan techniques described and the plaster study models. Hence <u>Null hyposthesis-1 is accepted</u>. It correlates well, with the similar study of Keating et al,[2] in which he compared plaster dental models with the laser scanned digital model in X, Y and Z planes. Our results are also in agreement with other studies like CavalCanti et al[27] who measured the difference between the CT images of dry skulls with that of original skull, Tomasetti et al[20] for measurement with quickceph software, HATS software and orthoCAD softwares compared to plaster models. **But** Quimby et al[29] and Santoro et al[28] had a significant difference for orthoCAD models measurements when compared to plaster models, they attributed the difference may be due to error in operator measurements and incorrect probe angulation. Moc et al[23] found statistically significant difference for mandibular model measurements when comparing

Digigraph and plaster model measurements which was attributed to instability of operators hand during digitization process

In **our study** plaster and reconstructed models had a statistically significant difference in all X, Y and Z planes (p = 0.001). Therefore, null hypothesis-2 was rejected. When digital models and reconstructed models were compared there was a statistically significant difference in Y (p = 0.002), and Z axis (p = 0.037); but in X axis (p = 0.093) the value is not statistically significant. It is in contrast to Keating et al[2] study, when they compared linear measurements of reconstructed dental model with plaster and digital model, it was not significant in X and Y plane, however it was statistically significant in Z plane. The dissimilarity between these studies may be attributed to varied 3D capturing techniques (laser scan Vs spiral CT scan), software analysis systems (RapidForm 2004 software program Vs MIMICS software) and reconstruction techniques (stereolithography Vs 3D printing)[2].

Our study indicated that there was significant difference in dimensional accuracy between reconstructed physical model replicas and plaster models. This is in agreement with Klein et al who reported Stereolithography (STL) model had dimensional inaccuracy, Lill et al who stated that Milled hard polyurethane foam model differed by 1.4mm from original model, Barker et al revealed in his study that Rapid Prototyping (RP) model differed from original model by 1.90mm, Kragslow et al revealed STL model in his study differed by 1.98mm[6]. J.Y.Choi et al[6] documented that RP model was more accurate in his study compared to Lill et al and Barker et al results, Timon Mallepree et al[46] published that his Quasi generated RP were not accurate.

Magnetic and optical storage are particularly efficient and cost effective when compared to traditional models. The size of the typical emodel file was 800 kilobytes and that of orthoCAD file was 3000 kilobyte[8]. Whereas the computed tomography file of each pair of three dimensional model was 650 Megabyte. The difference in the file capacity was due to the difference in the mechanism of scanning. The emodel scans the surface of the complete plaster model like in photocopying, whereas orthoCAD uses destructive scanning process that takes many scans of the model in thin slice[8]. The spiral CT scans not only the surface of the model but also the entire depth of the plaster models three dimensionally, even though it will not be useful to us. This is one of the drawbacks of CT scans. So in a single Compact disc, 900 e-models or 200 orthoCAD models can be stored but only one pair of computed tomography digital data can be stored.

Bill[20] et al in 1995, manufactured stereolithographic model of anatomical structures from the computed tomography digital data using computer aided manufacturing (CAM) technology. In this study CT data acquisition was performed using a SONATOM PLUS S with section intervals of 1mm, section thickness in spiral mode of 2mm and 512 X 512 matrix for sufficient resolution. The models were fabricated by the SLA-250 stereolithographic unit by polymerization of liquid U-V sensitive resin using a UV laser beam. The manufactured STL models had high precision and accuracy and aided in accurate treatment planning.

In **our study** dental models were reconstructed from three dimensional computed tomography data using Rapid Prototyping technology. Gibson[48] defined Rapid prototyping as a technology that allows the fast and automated fabrication of physical objects directly from virtual three dimensional computer aided design (3D-CAD) data without significant process planning related to part features and geometry. In our study, CT data acquisition was performed using a Siemens SONATOM Sensation 64 slice with section thickness of 0.5mm, the computed tomography data was converted into STL format and then rapid prototype model was produced by 3D printing technique of 1mm slice increment using Composite material.

In **our study** there was statistically significant difference in reconstructed model when it was compared to plaster model or digital model. The mean difference between plaster and reconstructed model was 1.80 $\pm$ 2.57mm ($p = 0.001$). The mean difference between reconstructed model and digital model is 1.83 $\pm$ 2.55mm. ($p = 0.011$). This is in accordance with the Barker et al study in which significant difference in dimensional accuracy was found in RP model replicated from CT scanning of a dry bone skull. They found a mean difference of 1.90mm (minimum -4.62mm, maximum 2.8mm)[6]. Errors in RP model can be caused by a wrong slice thickness, slice increment and related adjustments which can result in staircase effect or blurred edges or surfaces not well shaped.[6] Errors can also arise during the actual production and curing of RP models which include residual polymerization and transformation of RP materials, creation and removal of support structures, laser diameter, laser path, thickness of layer and finishing[6.]

However clinical significance of these errors will depend on the intended purpose of the reconstructed model. The models may not be sufficiently accurate for appliance construction but may be sufficient to demonstrate pre (or) post treatment occlusal relationship. Another limitation of this study is that only one pair of reconstructed model was evaluated because of cost factor.

The cervical margins in our digital study models are faintly visible and not very clear, this may be due to partial volume effect[46], image reconstruction algorithm[6], or due to increased radio density of plaster study models than bone. In Laser scanning technology they scan the model in many angulations and merge the images together to get a clear model with better cervical margins. In our study we used information of only one scan to reconstruct the model, further studies with various algorithms and merging of information from several scans of same model in MIMICS software must be done to improve the quality of cervical margin.

This study has presented a novel method of digitally recording study model data, offering the profession a valid alternative to the use of conventional plaster models which significantly reduced the burden of model storage. In addition the potential for physical reconstruction of a model from the digital data has been demonstrated for addressing medico legal concerns.

To assess the reliability and validity of digital and RP models, further studies has to be done with 3D Cone Beam Computed Tomography (CBCT) images, advanced software's and Rapid Prototype Model constructed with different materials (List 1), layering thickness and curing technique (List 2) .

List 1:

S. No.	**Various materials for reconstructing 3D models**
1.	ABS Plastic - Laser solidified
2.	Hard Wax
3.	Polymethyl methacrylate
4.	Titanium powder solidified with laser beam
5.	Hard paper

List 2:

S. No.	Various methods for reconstructing 3D models
1.	SLS – Selective Laser Sintering
2.	SLA - Stereolithography
3.	Inkjet Printing
4.	3D Printing
5.	LENS – Laser Engineered Net Shaping

Summary & Conclusion

SUMMARY AND CONCLUSION

The aim of our study was to assess the accuracy and reproducibility of using CT scan for capturing the surface detail of plaster models to create 3D digital models using MIMICS software and to evaluate the feasibility of producing accurate physical replicas from digital models using Rapid Prototyping.

The materials and method included 15 pairs of plaster models selected from department of Orthodontics, Ragas Dental College. All the 15 pairs of models were scanned using CT scan with single exposure and converted into digital virtual models using MIMICS soft ware. One physical reconstructed model was fabricated from the digital model by Rapid Prototyping. The plaster, digital and reconstructed models were compared for selected 20 linear measurements in X,Y and Z axis to assess the reliability, accuracy and reproducibility of the digital and reconstructed model with that of the plaster model. The inter examiner reliability of hand held Vernier caliper and the digital tools of MIMICS software were also assessed by comparing the repeat linear measurements made by two examiners in plaster, digital and reconstructed model. After statistical analysis of measurements we found that:

1. The conventional method of using hand held vernier caliper to measure plaster study models was reliable and reproducible as the difference between measurements by two examiners was not statistically significant.

2. The computed tomography scanner (Siemens SOMATOM Sensation 64 Slice) is a reliable device for capturing the surface detail of plaster study models three dimensionally in a digital format using the protocol described.

3. The measurement of on-screen 3D digital surface models using MIMICS software is reproducible as the difference between measurements by two examiners was not statistically significant.

4. The measurement of 3D digital surface models and plaster models of the same dentitions showed good agreement in all X, Y and Z axis as the measurements were not statistically significant.

5. The feasibility of fabricating 3D hard copies of dental models from the 3D on screen digital models is present.

6. The detail and accuracy of physical models, reconstructed from digital data may not be sufficient for certain applications, using the 3D printing method described. The reconstructed and plaster models were statistically significant in all three planes. The reconstructed and digital models were statistically significant in Y and Z planes; where as in X plane there was no statistical significance.

Bibliography

BIBLIOGRAPHY

1. **Akther Hussain MDS**. Clinical Aid –Imaging of plaster casts with a flat bed scanner. J Clin Orthod. 2008; 6; 393-399.

2. **Andrew P. Keating, Jermy Knox.** A comparison of plaster, digital and reconstructed study model accuracy. J Orthod 2008;Sep,Vol 35,191-201

3. **Boot Vong Z.Liu, C.Mc.Grath, U.Hagg; Ricky.** Virtual model analysis - An alternative approach to plaster Model analysis: Reliability and validity. Eur J Orthod 2010, Vol 32,589-595.

4. **Budi Kustono DDS,MS and Carla Evans, DDS,DMsc.** Reliability of a 3D surface laser scanner for Orthodontic applications.
   Am J Orthod Dentofacial Orthop. 2002;122:342-8

5. **Chi Zari.M, Wang.B.** 3D numerical analysis of an ACC reconstructed knee. 2009; Simulia, Customer conference.

6. **Choi J-Y, Choi J-H, Kim K.** Analysis of errors in medical rapid prototyping models. Int J Oral Maxillofac Surg 2002: 31:23-32.

7. **Chung How Kau,Jay Little Field, Neal Rainy, Jennifer T.Nguyen,Bencreed.** Virtual model analysis as an alternative approach to plaster model analysis: reliability and validity. Eur J Orthod 2010 Feb; 17.

8. **Daniel S.German DDS, Julia German.** Cone-Beam volumetric imaging: a two minute drill. J Clin Orthod 2010: XLII; NO 4:253-65.

9. **Daron R.Stevens,Carlos Flores-Mir,Brian Nebbe.** Validity, reliability and reproducibility of Plaster Vs digital study models: Comparison of peer assessment rating and Bolton analysis and their constituent measurements. Am J Orthod Dentofacial Orthop 2006;129:794-803

10. **Demetrios. J.Halozonetis, DDS,MS,Dr Odont.** Acquisition of three dimensional shapes from images. Am J Orthod Dentofacial Orthop May 2001;119;5:351-57

11. **Delong, Heinzen, Hodges, Douglas.** Accuracy of a system of creating 3D computer models of dental arches. J Dent Res 2003:82(6): 438-442

12. **Dong-Soon-Choi, Young-Mok Jeong, Insan jang.** Accuracy and reliability of palatal superimposition of three Dimensional digital Models. Angle Orthod; 2010:80:685-691.

13. **Efuniger, Dieter Kruse.** CAD by processing of computer tomographic data and CAM of individually designed prosthesis. Int J Oral maxillofac Surg 1995;24:90-97

14. **Eldo Markose, Vikraman, Veerabahu.** Three dimensional CT reconstruction - A comparison between 2D, 3D CT and original anatomical structures. J Oral Maxillofac Surg 2009; 8(1):8-12.

15. **Federico Cesarani, Maria Cristina Martina.** Facial reconstruction of a wrapped Egyptian mummy using MDCT. American AJR 2004;183;755-758.

16. **Gwen. R.J.Swennen, Wouter Mollemans.** Three dimensional treatment planning of orthognathic surgery in the era of virtual imaging. J Oral Maxillofac Surg 2009;67:2080-2092.

17. **Hajeer, Millett.** Current products, practices, applications of three dimensional imaging in orthodontics. Part II. J Orthod 204;Vol 31:154-162

18. **Haut huille, F.Taha.** Comparison of two computer assisted surgery techniques to guide a mandibular distraction osteogenesis procedure – technical note. Int J Oral Maxillofac Surg 2005;34:197-201.

19. **IBiTech, Ghent University, Belgium.** Optimizing stent design with the use of MIMICS and numerical stimulation. Materialise NV, 2010.

20. **James J. Tomasetti, Louis J. Taloumi.** A comparison of 3D computerized Bolton Tooth-Size Analysis with a commonly used method. Angle Orthod 2001:Vol 71:351-357.

21. **James Mah and Axel Bumann.** Technology to create the three dimensional patient record. Sem in Orthod 2001;7: 251-257.

22. **Joseph.s. Bill, Juren F.Reuther, Werner Dittman.** Stereolithography in oral and maxillofacial planning. Int J Oral Maxillofac Surg 1995;24:98-103.

23. **Kevin.H.Y.Mok and Michael S.Cooke.** Space analysis: A comparison between Sonic Digitization (Digi Graph)^{TM} work station and digital caliper. Eur J Orthod 1998;20:653-661.

24. **Khemachit Sena, Surasith Piyasin.** Determination of average of contour Thai skulls for design of implants. American J. of Engineering and Applied Sciences 2008; I(3);168-173.

25. **Lei Lu DDS, Hang Wang DDS**. Individual design and rapid prototype in reconstruction of orbital wall defects. J Oral Maxillofac Surg 2010;68:562-570.

26. **Li WZ, Zhang MC.** Application of computer aided three dimensional skull model with rapid prototyping techniques in repair of zygomatico-orbito- maxillary complex fracture. Int J Med Robot 2009;Jun 5(2);158-163.

27. **Marcelo G.P. Cavalcanti, John W. Haller.** Three dimensional computed tomography landmark measurement in craniofacial surgical planning. Experimental validation in vitro. J Oral Maxillofac Surg 1999; 57; 690-694.

28. **Margherita Santoro, Scott Galkin.** Comparison of measurements made on digital and plaster models. Am J Orthod Dentofacial Orthop 2003;124:101-105

29. **Meredith L. Quimby, DDS, MS; Katherine W. L. Vig, BDS, MS, FDS, DOrth.** The Accuracy and reliability of measurements made on
computer-based digital models. Angle Orthod 2004;74:298–303.

30. **Nkenke E, Zachow S.** Fusion of computed tomographic data and optical 3D images of dentition for streak artifact correction in simulation of orthognathic surgery. Dentomaxillofacial radiology 2004; 33;226-232.

31. **Nobuyoshi Motohashi and Takayuki Kuroda.** A 3D Computer- aided design system applied to diagnosis and treatment planning in orthodontics and orthognathic surgery. Eur J Orthod 1999; 21:263-274.

32. **Noortije I Regensburg, Pauline.** A new and validated CT based method for calculation of orbital soft tissue volumes. Invest Ophthalmol Vis Sci; 2008;49;1758-1762.

33. **Pham A.M., Rafi A.A.** Computer modeling and intra operative navigation in maxillofacial surgery. Otolaryngol Head Neck Surg; 2007, Oct 137(4): 624-31.

34. **Ronald Redmond.** The digital orthodontic office. J clin Orthod 2001: vol 7 no4 Dec:266-273.

35. **Ronald Redmond.** Cutting edge – computer based fabrication of occlusal splints. J clin Orthod 2008; Vol XLII: no 4, 227-31.

36. **Ronald Redmond.** Cutting edge - the advantage of offsite backups. J clin Orthod 2008: vol XL II no4 Dec: 457-60.

37. **Redmond, Mah.** The cutting Edge - The evolution of Digital Study models. J clin orthod vol XL; No9 2006:sep:531-537

38. **Redmond.Boutin.** The cutting edge - Internet Based treatment planning and communication. J clin orthod Vol XLI 2006;Sep:531-537.

39. **Redmond , Ravenkar, Gandedkar, Ganeshkar.** The cutting edge J clin Orthod2009 Vol XLII no.6:393-399.

40. **Santoro M, Ayoub ME, Pavdi V, Cangiolosi.** Mesiodistal crown dimensions and tooth size discrepancy of the permanent dentition of Dominician Americans. Angle Orthod 2000; 70:303-7.

41. **Sean Curry, Sheldon Baumrind, Sean Carlson.** Integrated three dimensional craniofacial mapping at the Craniofacial Research Instrumentation Laboratory/ University. Sem In Orthod 2001, Vol 7, Dec:266-273.

42. **Schrimer Ur, WhiltShire.** Manual and computer aided space analysis: A comparative study. Am J Orthod Dentofacial Orthop1997;112:676-80.

43. **Sridevi Padmanaban, B.Vikraman.** Evaluation of the accuracy of linear measurements on spiral computed tomography – derived three dimensional images and its comparison with digital cephalometric radiography. Dentomaxillofacial Radiology 2010;39: 216-223.

44. **Stephen Jacobs, Ronny Grunert.** 3D imaging of cardiac structures using 3D heart models for planning in heart surgery – A preliminary study. Interact Cardio Vasc Thorac Surg 2008;7;6-9.

45. **Takayuki Kuroda, Nobuyoshi Motohashi.** Three dimensional dental cast analyzing system using laser scanning. Am J Orthod Dentofacial Orthop 1996, 110:365-9.

46. **Timon Mallepree, Diethard Bergers.** Accuracy of medical RP models. Rapid prototyping journal 2009;15/5; 325-332.

47. **Verelinck L, Politis C.** Image based planning and clinical validation of zygoma and pterygoid implant placement in patients with severe bone atrophy using customized drill. Int J Oral Maxillofac Surg 2003; 32; 7-14.

48. **Vishal Dang.** Focus on cone beam computed tomography. Dental practice 2009: Vol 9, No1:10-12.

49. **Yoon-Ah Kook, Seong-Hun Kim, Sun-Seo Ho.** A simple technique for independent torque control with mini screw anchorage. J clin Orthod 2009: Vol XI III No 6:393-399.